Middlesex University London

Middlesex University Research Repository

An open access repository of

Middlesex University research

http://eprints.mdx.ac.uk

Bradshaw, Noel-Ann (2019) Innovations designed to improve the student experience for mathematics students in higher education. [Doctorate by Public Works]

Final accepted version (with author's formatting)

This version is available at: https://eprints.mdx.ac.uk/26856/

Copyright:

Middlesex University Research Repository makes the University's research available electronically.

Copyright and moral rights to this work are retained by the author and/or other copyright owners unless otherwise stated. The work is supplied on the understanding that any use for commercial gain is strictly forbidden. A copy may be downloaded for personal, non-commercial, research or study without prior permission and without charge.

Works, including theses and research projects, may not be reproduced in any format or medium, or extensive quotations taken from them, or their content changed in any way, without first obtaining permission in writing from the copyright holder(s). They may not be sold or exploited commercially in any format or medium without the prior written permission of the copyright holder(s).

Full bibliographic details must be given when referring to, or quoting from full items including the author's name, the title of the work, publication details where relevant (place, publisher, date), pagination, and for theses or dissertations the awarding institution, the degree type awarded, and the date of the award.

If you believe that any material held in the repository infringes copyright law, please contact the Repository Team at Middlesex University via the following email address:

eprints@mdx.ac.uk

The item will be removed from the repository while any claim is being investigated.

See also repository copyright: re-use policy: http://eprints.mdx.ac.uk/policies.html#copy

INNOVATIONS DESIGNED TO IMPROVE THE STUDENT EXPERIENCE FOR MATHEMATICS STUDENTS IN HIGHER EDUCATION

Noel-Ann Bradshaw CMath FIMA

A project submitted to Middlesex University in partial fulfilment of the requirements for the degree of Doctor of Professional Studies Institute for Work Based Learning
Middlesex University.

May 2019

Disclaimer: The views expressed in this document are mine and are not necessarily the views of my supervisory team, examiners or Middlesex University.

Abstract

In this context statement I research my public works in mathematics education and the impact they had on my practice, my students and my field at both national and international level. The works I am analysing are: The Maths Arcade, Tomorrow's Mathematicians Today Undergraduate Conference, various employability initiatives, and a selection of videos and screencasts designed to improve students' thinking. It includes some of the pedagogical theory that surrounds my works, details the social and political landscape associated with UK higher education, and discusses my motivations. In summary, it investigates the reasons I initiated these activities and answers the question why it is only I that could have done this work.

In analysing my public works I use autoethnography alongside critical reflection, drawing on my own experience of studying for a mathematics degree as a mature student with non-standard entry qualifications. I discuss the problems incurred by adults who have had a speech impediment when younger and the difficulties experienced by first-generation entrants to higher education. This research has shown that the underlying theme behind these initiatives is transition; transition into HE, transition between years and finally transition out of HE.

From my research I conclude that it is not so much the works themselves that are important but the underlying strategies and motivations. For students transitioning from school to university this includes the need to form strong friendships with their peers and to take part in activities that promote good staff/student interactions and communities. For students transitioning between years it includes developing independent learning and problem-solving skills, and for those transitioning into work or further study it includes the need to actively engage in career management. I hope that this research will enable other institutions and academics to initiate similar activities designed to improve the student experience for their cohorts of students.

In Memoriam

In memory of Justin Williams (Rhys Oliver Thomas), one of my first cohort of students at the University of Greenwich; an inspiration to me and many others.

Dedication

I would like to dedicate this work to my four amazing children: Joshua, Karen, David and Isaac. My life would be meaningless without you. Thank you for putting up with having a mathematician as a mother.

Acknowledgements

I am very grateful to the University of Middlesex and Dr Kate Maguire for giving me this opportunity to pursue research around my public works. I would like to thank my supervisor Dr Nico Pizzolato and advisor Dr Alison Megeney for all their support, guidance, advice and inspiration during this research journey.

However, I would not have got to this point in my career were it not for the University of Greenwich giving me the initial chance to obtain an undergraduate degree. I would particularly like to thank Tony Mann, Ashley Hoolash, Dr Chris Walshaw and Dr Cos Ierotheou; without their belief and encouragement, I would have struggled to complete my studies.

Other inspirational people in my career to date have been Professor Liz Bacon, Professor Judith Burnett, Professor Mark O'Thomas, Dr Simon Walker, Professor Neil Challis, Dr Jeff Waldock, David Youdan and Michael Grove. Their career guidance, support and encouragement have helped me get where I am. I am also indebted to all those who have collaborated with me on projects (and have not been named previously). In particular Dr Peter Rowlett, Dr Claire Cornock, Erica Tyson, Elena Moreno, Matthew Conneally and Helen Carpenter.

I also acknowledge that without the support of my friends and family I would not be the person I am nor achieved what I have. I would like to thank my adoptive parents, Frank and Daphne Sutton, without whom I would not have had the education and early experiences that helped to shape my formative years and thus influenced the creation of these public works. I am grateful to my ex-husband, Steve Bradshaw, and children, Josh, Karen, David and Isaac for all their support and encouragement; without this I could not have started and completed my undergraduate degree. More recently I am very grateful to Tony Mann and Jonathan Histed for helping to proof-read this thesis and offering the necessary support needed to get this completed.

And lastly, I would like to thank all the students who have contributed to these works either through participating, providing feedback or helping to run events. There are far too many of you to name, but you know who you are; these works could not have happened without you.

Contents

List of Tables

Glossary

ACH	Architecture, Computing and Humanities
ACME	The Advisory Committee on Mathematics Education
A-level	Advanced Level
AMSP	Advanced Mathematics Support Programme
APT	Academic Practice and Technology
AS-level	Advanced Subsidiary Level
BAMC	British Applied Mathematical Colloquium
BAME	Black, Asian and Minority Ethnic
BERA	British Educational Research Association
BMC	British Mathematical Colloquium
BSA	British Stammering Association
BSHM	British Society for the History of Mathematics
CBI	Confederation of British Industry
CETL	Centres for Excellence in Teaching and Learning
CIMA	Chartered Institute of Management Accountants
CMS	The Council for the Mathematical Sciences
DLHE	Destination of Leavers of Higher Education Survey
EC	Extenuating Circumstances
ECS	Employability and Careers Service at University of Greenwich (post 2015)
EDU	Educational Development Unit
ELBA	East London Business Association
EMS	Edinburgh Mathematical Society
FE	Further Education

FMSP	Further Mathematics Support Programme
GCHQ	Government Communications Headquarters
GCSE	General Certificate of Secondary Education
GET	Guidance and Employability Team at University of Greenwich (pre 2015)
GSK	GlaxoSmithKline
HE	Higher Education
HEA	Higher Education Academy
HEFCE	Higher Education Funding Council England
HEFCW	Higher Education Funding Council Wales
HEI	Higher Education Institution
HESA	Higher Education Statistics Agency
HESTEM	National Higher Education Science, Technology, Engineering and Mathematics Programme
HND	Higher National Diploma
IMA	Institute of Mathematics and its Applications
JMC	Joint Mathematical Council
KIS	Key Information Set
LMS	London Mathematical Society
MASH	Mathematics and Statistics Help
MEI	Mathematics in Education and Industry
MSOR	Mathematics, Statistics and Operational Research
MWP	Mathematics Work Placement
NSS	National Student Survey
ONS	Office of National Statistics
ORS	The Operational Research Society

PDP	Personal Development Planning
PVC	Pro-Vice Chancellor
QAA	Quality Assurance Agency
RS	Royal Society
RSS	Royal Statistical Society
SHU	Sheffield Hallam University
STEM	Science, Technology, Engineering and Mathematics
T&L	Teaching and Learning
TEF	Teaching Excellence Framework
THE	Times Higher Education
TMT	Tomorrow's Mathematicians Today undergraduate conference
UAS	Undergraduate Ambassador Scheme
ULO	University Liaison Officer for the IMA
UWE	University of the West of England

1. Summary and introduction

"*Education is the great engine of personal development. It is through education that the daughter of a peasant can become a doctor, that the son of a mineworker can become the head of the mine, that a child of farm workers can become the president of a great nation. It is what we make out of what we have, not what we are given, that separates one person from another*." Nelson Mandela, First Democratically Elected President of South Africa (1994, p.9).

I first encountered university life as a mature student in 2004. I was an unemployed housewife bringing up four children in South East London, UK. Whilst training as an adult numeracy teacher my tutor advised me to apply to university. Since then, more than 14 years later, I have taught over a thousand students, published numerous articles, instigated several student-focussed projects, given hundreds of talks and workshops, edited a Higher Education (HE) Mathematics Education journal, become a member of a university Faculty Senior Management Team, been elected Vice President of the Institute of Mathematics and its Applications (IMA) and, more recently, taken up the role Data Scientist and Operational Research Specialist for a large UK retailer.

How and why I made this life-changing transformation from someone with little focus and prospects to a highly valued and respected education professional in the mathematics community is documented in the following chapters. This journey has necessitated learning and developing numerous new skills to enable my transition from one role to another. My reflections on this journey have identified that the majority of my student-focussed interventions have also been concerned with transitions: transition from school to university, transition between university years and then finally the transition from student to graduate employee. Interestingly my own journey is far from over as I have recently made another transition; this time from HE to industry. Applyby and Cox (2002, pp.3, 16, 17) describe transition as a "difficult and uncertain process … that will always cause some problems for students or any of us". They conclude by saying that as educators we should "aim to reduce the likelihood of these problems, diagnose those that remain and offer support to those affected". This sums up the motivation behind my public works.

1.1 My public works

My public works focus on four projects or groups of projects. The first is the Maths Arcade (4.2). This is an extra-curricular drop-in session for mathematics students that I initiated at Greenwich in 2010. It has been adopted and modified by at least 10 UK universities and is designed to help students develop mathematical thinking, and communication skills (4.2.2). It has become a useful tool to help new first year students transition into university life.

The second is the UK student mathematics conference Tomorrow's Mathematicians Today (4.3). This is a one-day conference that initially took place in 2010 at University of Greenwich and was subsequently adopted by the IMA to enable it to run annually in a variety of venues. The conference has gained support and sponsorship from many sources, including GCHQ, who traditionally sponsor the best paper. Designed to help prepare students to transition from student to research mathematician and/or employable professional, it provides presenters (students from a wide variety of institutions) with exposure to public speaking, planning talks and researching a topic in enough depth to be able to communicate its message to those who are not so familiar with it. Previous speakers at TMT have fed back how useful the experience has been in helping them obtain a graduate-level job (4.3).

Organising TMT and seeing my first cohort of students successfully transition from new undergraduates to confident mathematicians made me realise that they also needed preparing for the next transition of being catapulted into the professional workplace (2.6.2, 4.4). As a result, I instigated a range of activities at Greenwich to help students understand their own starting points, reflect on their journey, find out about available options and gain the skills and confidence necessary to make successful applications (4.4, 4.4.3). These projects included a mock assessment centre activity: The IMA Business Game; an event called *Maths Graduates: Where are they now?;* an employer-endorsed assignment incorporating a mock job application and a new final year module, *Data Analytics*, co-created with industry involvement, and designed to help students gain various technical and soft skills necessary for the workplace (4.4).

My involvement in student employability has not been confined to mathematics students. In 2015, I was appointed the Director of Employability for students in the largest multi-discipline faculty at Greenwich: The Faculty of Architecture, Computing and Humanities (ACH). In this role, I devised and put in place an employability framework for staff to adopt across all undergraduate degree programmes (4.4.3). This was used to help students understand where in the curriculum they have gained certain skills to enable them be more successful in the graduate recruitment process and competency-based interviews.

My final public work is based around my use of technology in learning (4.5). This has involved creating screencasts and videos to help explain difficult concepts to students in order to develop their mathematical thinking. Rather than just showing students a worked solution to a problem with only written explanation, these resources enable me to talk through the problem allowing the students to hear my thoughts unfold, enabling them to develop their own thinking.

1.2 Research Methodology

The aim of this context statement is to provide the theory and background for my public works. This was undertaken initially for my own development, to enable me to gain a better understanding of the reasons for and impact of the success of my public works. However, as my research progressed, I appreciated that this might also be of benefit to other practitioners, helping to guide and motivate them. This statement documents the research and some of the pedagogical thinking and theories that surround my works; it discusses the social and political landscape associated with the issues arising, and investigates my motivations. The ultimate goal is to provide fresh insight into concerns such as widening participation, issues faced by mature students and first-generation entrants to HE and the effect of speech impediments on the behaviour of children and adults. Whilst I am aware that much of this might be of interest to HE professionals from a variety of disciplines, it has been predominantly written for a mathematical audience given the context of my works.

When I embarked on this work I did not intend to write such a self-absorbed second chapter. I like to think of myself as an analytical mathematician; I crave order and control, particularly when tired or under stress, and try to look objectively at political, social and cultural issues. However, it became apparent that when trying to answer the question "Why have I done what I have in my professional career?" that this could only be answered using research methods that some mathematicians, and indeed some social scientists, might describe as "navel-gazing" but what others term autoethnography (Allen-Collinson and Hockey, 2008, p.209). This research methodology will be largely alien to the research mathematician who sees very little connection between their personal life and their scholarly interests (Anderson, 2006) and indeed this was my initial reaction. However, I now realise that, in order to gain insight into one's published works, it is necessary to understand one's self (Anderson, 2006). Grove and Kyle (2018) discuss some of the concerns that research mathematicians encounter with qualitative educational research which results in non-quantifiable, variable conclusions. They observe that the more familiar one becomes with this genre of research the more fluency the researcher will achieve. I hope that this context statement demonstrates this fluency.

1.2.1 Autoethnography as a framework for critical reflection

In my pursuit to analyse why I have done what I have and learn from it, I have used a mix of analytical and evocative autoethnography alongside critical reflection. This means that in some places I have relied solely on my subjective experience whereas, elsewhere, I have reached beyond this to engage with the literature to help me contextualise them (Anderson, 2006). Although autoethnography was not a methodology I was familiar with at the start of my research journey it is one that several leaders of professional doctoral research programmes advocate. Hayes and Fulton (2015) state that autoethnography has a particular legitimacy within professional doctoral studies where there is a need to move beyond theory to enable the author to focus on practice in the context of their employment and recollections. They go on to conclude that autoethnography allows for the illumination of "a critical view of their own selves, and to bring a degree of intellectual objectivity into what can then become a shared interdisciplinary perspective" (Hayes and Fulton, 2015, p.12). McIlveen (2008, p.1) recommends the use of "autoethnography as a qualitative method of reflexive enquiry for narrative research and practice that specifically addresses the stories of the scientist and the practitioner." Critical reflection and reflexive enquiry are defined by Boyd and Fayles (1993, p.100) as "the process of internally examining and exploring an issue of concern, triggered by an experience, which creates and clarifies meaning in terms of self, and which results in a changed conceptual perspective". Fook (2007, p.441) explains in more detail the difference between reflection and critical reflection emphasising that critical reflection is about having the ability to transform, leading to a fundamental change in perspective. It is this continual and cyclical questioning of one's own experiences to gain meaning and inform and change one's perspectives and actions that I employed throughout my career and have actively encouraged students to use and practise. In the past I have pursued this through active, practitioner-led research projects (3.2.4) that I have reviewed and critiqued primarily using student feedback, current literature and colleague observations and discussion. These have then, in turn, improved my knowledge and understanding both of self and theory, enabling me to modify my practice. It is important to note that I, like many others, frequently use the term 'reflection' when 'critical reflection' or 'reflexive enquiry' might be more accurate terminology. However, given the context, I acknowledge I have used the terms loosely to make it easier to read.

In critically reflecting on my public works I now realise that I have viewed them utilising Brookfield's lenses (1998): students, colleague perception, theory and autobiographical experience using the corresponding tools: student feedback, peer-review, reading the literature and self-reflection. Brookfield advocates the use of these lenses in order to enable the researcher to detect any assumptions that they are making. Considering this, Stein (2000, p.1) further defines critical reflection as being "the process by which adults identify the assumptions governing their actions, locate the historical and cultural origins of the assumptions, question the meaning of the assumptions, and develop alternative ways of acting". Being aware of these assumptions and using the vehicle of autoethnography I have been able to perceive how my early childhood experiences have informed my values and thus coloured the choices and decisions I make. For example, in the past, this may well have led to my giving more weight to feedback from students who I perceived as being disadvantaged in some way or having been swayed more by colleagues from similar institutions to my own. Interestingly I now see that these assumptions are linked to the concept of unconscious bias (5.1.1) which I am involved in highlighting at my current workplace. If I was to go back into the education sector this is an area that I would want to explore in more detail.

1.2.2 What is autoethnography?

A key attribute of autoethnography is that the researcher is themselves part of the study, and therefore able to draw on their own experience and behaviour to understand more about the world around them (Ngunjiri, Hernandez and Chang, 2010). This is in direct contrast to the approach described by Maso (2001) where the world is deliberately viewed objectively. Ellis, Adams and Bochner (2011, p.273) explain this as being “an approach to research and writing that seeks to describe and systematically analyse (graphy) personal experience (auto) in order to understand cultural experience (ethno).” This concept is at the heart of my context statement.

Autoethnography is not a research methodology commonly used by teachers in HE, which may be, in part, due to the perceived risk involved in making one’s thoughts and practice visible and open to scrutiny, although this must also be a risk in other professional situations where third parties (students, patients etc) are involved (Trahar, 2012). Making one’s thoughts and practices open to scrutiny has the potential for exposing the researcher to uncomfortable vulnerability (Pillay, Naicker and Pithouse-Morgan, 2016). Despite this, using autoethnography as an HE professional has enabled me to better understand my motivations behind my innovations, and subsequently link these with the theories of learning and teaching with which I was already familiar. I have found this methodology to be an excellent way to closely examine what I believe and why I believe it. Echoing the words of Trahar (2012, p.371), I have found it has been “through the autoethnographic process that the social and cultural aspects of my own life and my held beliefs about learning and teaching have been – and continue to be – exposed and questioned.” I also identify with the sentiments of an elementary teacher, Pennington (2007), who recognises that autoethnography has been crucial to understanding her students’ perspectives along with her own.

Reflecting on this further, I have been reminded that when trying to explain to students how they should write reflective journals on their work-based placements I frequently encouraged them to ask themselves the question “So what?” after describing an incident. Those that did this found it enabled them to discover, and then better articulate, the effect of their actions or thought processes. I now find that my inner voice regularly asks myself the question “Why?” when I have described something that I have done: “Why did I do this? Why did I do it that way? Why has it had this result? Why did students react as they did?”. Like Trahar (2012) I have found using autoethnography has been a self-illuminating process that has enabled me, both as a practitioner and a researcher, to identify key experiences in order to understand their consequences and thus motivate myself, and potentially others, to action.

I believe my unique background and experiences have made a significant contribution to the formation of my public works. Whilst being unique, they also draw on several areas that others have researched and declared interest in. I consider it has been important to explore these experiences and enable the resulting conclusions to be heard. To enable me to reflect on why I have created the works that I have done, I realise that I needed to understand the beliefs that I hold and the self-imposed ethical framework within which I operate. This means that I had to reflect on my experiences as a stammerer, a mature student, a mathematics student from a non-traditional background (i.e. without A-level mathematics) and then identify what they add to me as a lecturer. It is this that sets autoethnography apart from other autobiographical accounts; having myself, the author, as part of the research group under scrutiny. Consequently, delving into my childhood experiences will help shed light on issues faced by stammerers and those who find it hard to engage with the traditional school system. Examining my experiences as a mature student will allow further insight about mature students to become evident. These in turn will help to illuminate my motivations and pedagogies behind my works.

1.2.3 My use of autoethnography

To use this methodology, I delved into old diary entries, spoke to close collaborators and reread papers that myself and others had written about the works I had created. I then reflected on my journey into HE and, through doing this, realised that some of my childhood experiences, along with my experience of being a mature student, explained many of my subsequent behaviours and the importance I have placed on helping improve student transitions and the student experience in general. When reflecting on the individual public works it became apparent that there were elements of my own experience that were useful to understanding cultural and social experiences and vice versa as Ellis et al. (2011) describe (Chapter 4). For example, the Maths Arcade grew out of my own experience of mathematical games and puzzles seeming to improve my strategic thinking, and my realising that, whilst on my degree, I had benefitted from social interaction with my peers and lecturers. Thus, when looking for something that helped develop students' mathematical thinking, whilst at the same time promoted friendship and communication (attributes that do not always come naturally to mathematics students (Waldock, Rowlett, Cornock, Robinson and Bartholomew, 2017)), the Maths Arcade was devised (4.1). Having undertaken this research I have realised that these cultural insights, discussed in Chapters 2 and 4, should be helpful for many working in HE or in the broader education sector and, in particular, those involved in the teaching of mathematics students. Thus, this context statement has been written with a mathematical educator in mind as the reader.

It is important to be aware that autoethnography is not without its critics. According to Allen-Collinson and Hockey (2008) criticism tends to focus on the problem of its lack of objectivity, due to using one's self as a data source, and thus the temptation to be irrational and self-indulgent. As someone spending most of their time developing analytical models to solve business-related problems I see rigour as being crucial. Le Roux (2017, p.196) cites Karp arguing that "the value and vitality of research depends on its providing theoretical illumination of the topic under investigation. The goal of research should be to educate and inform, that is, to develop and advance knowledge and thereby make a contribution to society."

What constitutes rigour in qualitative research is also discussed by Le Roux (2017) who asserts that firstly one needs to stipulate the goal of the research. Once this has been established, one can then identify appropriate multiple criteria for evaluating and assessing its validity. Having worked on evaluating mathematical multi-objective and multi-criterion problems, it was easy to see that this was also necessary in qualitative research. Researchers have attempted to create lists by which qualitative research can be measured (Tracy, 2010). Le Roux (2017) details some of these and even suggests her own, including: worthy topic, rich rigour, sincerity, credibility, resonance, significant contribution, ethical, meaningful coherence whilst acknowledging that these must be based within the context that the research sits.

As stated before, one of the goals of this research is to provide fresh insight into various concerns in HE that are relevant to the creation of my public works. This autoethnographical approach has enabled me to engage with the theories around topics such as retention and graduate employability whilst putting it into the context of "my story" allowing me to "concentrate on ways of producing meaningful, accessible and evocative research grounded in personal experience" (Ellis et al., 2011, p.274).

Understanding my upbringing and mathematical journey to date has enabled me, and hopefully the reader, to understand why I considered it necessary for new first year mathematics students to develop effective communication skills and form friendships. At the time, I thought it was purely down to my experience as a mature student and my reading relevant literature. Now, having used autoethnography and critical reflection to examine my early motivations and values, I can see more clearly the influence of my early educational and social experiences and better understand how they have changed my subsequent professional behaviour and ethical decision making.

The personal experiences I have chosen to recount are very much epiphanies or turning points that, not only made a significant impact on my life at the time (Bochner and Ellis, 1992), but were also pivotal in the creation at least one of my public works. I acknowledge that these epiphanies are very personal and self-claimed so, whilst I consider them transformative in some way, others might not see this so easily (Bochner, 1984). My approach is summed up by the following, somewhat lengthy, quotation from Bochner and Ellis (1996, p.4) where they seek to explain how ethnography is changing from description to communication as we move into the twenty-first century. “Interactive ethnography privileges the way in which investigators are part of the world they investigate and the ways in which they make it and change it. ... For writers whose work departs from canonical forms of narrating ethnography, there is a desire to be more author centred and, at the same time, more engaging to readers. Forms and modes of writing become part and parcel of ethnographic method. The goal is not only to know but to feel ethnographic truth and thus to become more fully immersed – morally, aesthetically, emotionally and intellectually.”

When discussing my public works (Chapter 4) I have started each section with an excerpt from my professional diary in a similar vein to Pitard (2016) and Warren (2016). Whilst not providing any great insight, this hopefully sets the scene bringing it alive to the reader. I then explain the context behind the excerpt and describe the work in more detail whilst drawing on my past experiences where relevant.

This research style will be as unfamiliar to my mathematical colleagues as it was to me at the start of this journey. A pure mathematician tends to start with a theory that they want to prove using various mathematical constructs. An applied mathematician often starts with a problem that they want to solve, simplify or optimise. This can involve designing a model, writing some code and running experiments to test and validate the model. None of these approaches require much reflection into personal practice.

Mathematics is often considered by some to be rather dry and only able to be taught using classical methods of “talk and chalk”. Whilst many seek to convey the beauty of mathematical concepts in their lectures and writings, it is fundamentally a science and one does not sit around and discuss how one “feels” about it in the same way as one might with other disciplines. I hope that this new perspective that autoethnography and critical reflection has given me on my public works will also enable others to reflect and learn from their work and experiences as much as mine.

1.3 Summary

This context statement contains five chapters. This first chapter has provided an overview of my public works that I have submitted for consideration for this award. It also summarises the research methodologies used; autoethnography and critical self-reflection and the benefit that this can bring both for myself and also the target audience. It describes the benefit of using autoethnography and critical self-reflection citing other similar examples in doctoral research programmes and specifically within Teaching and Learning in Higher Education. At the same time, it acknowledges some of the criticisms of this as a methodology that appear in the literature.

The second chapter primarily uses evocative autoethnography to reflect on relevant aspects of my background explaining what it is about my personal history that has led me to create these works. It is written as layered autoethnographic account where layered refers to "a back-and-forth movement between experiencing and examining a vulnerable self and observing and revealing the broader context of that experience" (Ellis 2007, p.14). It includes details of the obstacles and motivations that have shaped my practice and answers the question "Why have I done this work and not someone else?". It also addresses what it means for me to be a professional in my field including my values, my professional mindset, my modus operandi.

Chapter three sets out the context within which my works are set using analytical autoethnography and critical reflection in a layered autoethnographic account. In this I delve into the literature and data concerning the ideological, cultural and political framework surrounding UK education and specifically that of Higher Education (HE), whilst at the same time drawing on my own personal experience. I include information on some of the areas that are particularly pertinent to my pedagogic research such as retention, employability, student engagement. I start by recounting the changes that HE has experienced in the last 30 years moving from being a provider of "elite" to "mass" education and then progresses to examining mathematics as a discipline; what it is, how it is perceived by the general public and how it is taught and learned at university. Included in this is a section on the learning theories that I have found particularly helpful to my work and another on the discipline-based pedagogical research. I then go on to reflect on various issues faced by mathematics departments and students, as detailed in the literature, such as transition and employability. It also includes (for the reader from a non-mathematical background) a summary of the different mathematical organisations which are specifically relevant to my work and journey. The chapter concludes with a reflective discourse on the Department of Mathematical Sciences at the University of Greenwich where I began my HE career, and details of my collaborations across the sector.

Chapter four examines my public works, taking each one in turn, critically discussing both the significance and impact in the sector and beyond, and showing how the research methodologies used have helped to identify these. This is followed by a critique of each one in the context of the literature and further work. Each section starts with a short extract from my diary setting the scene and showing how the initial ideas behind the works began.

The final chapter provides a conclusion to this work identifying several key themes that will be useful for HE staff wanting to implement similar activities for their students. It ends by looking at potential next steps that could be taken to further improve the student experience for mathematics students in HE.

2. Professional Self

"*One thing we do not seem to learn from experience, is that we seldom learn from experience alone*." John Mason (2002, p.58).

This chapter is written as a layered autoethnographic account. It uses a mix of evocative autoethnography and reflection on my early education and values, recounting my unusual journey into academia, seeking to answer the question why it is only I that could have created these public works. The leap from an eighteen-year-old with just one A-level (grade E in Home Economics) to a lecturer in mathematics followed by progression to member of Faulty Senior Management at the University of Greenwich and Vice President of a leading professional body demonstrates that, with the right motivation and encouragement, anything is possible.

2.1 Educational background

I was educated in the same all-girls independent school in Surrey between the ages of 5 and 18. It should have been a fantastic opportunity for any inquisitive child and especially one with a leaning towards science and maths. However, at the time, too much of it focused on unsuccessful and painful interactions with other girls in my class and lessons that frequently seemed irrelevant. Neither of my parents had been to university, and indeed both left school at 14; one to attend secretarial college and the other to enter the Civil Service. They assumed that the school would do everything necessary to educate me and enable me to gain a place at university. They failed to understand how they could support and augment the school's provision or, crucially in my case, that sometimes teachers and schools can make mistakes.

This lack of parental foresight is similar in its origins and consequences to that displayed by parents of current first-generation HE students. It is not that these parents are unwilling to help and support but, without having had these educational experiences themselves, they fail to understand the pressures that they bring. Coupled with this is the fact that the young person concerned is often unable to articulate their needs as they do not fully understand them. This is discussed further in Thomas and Quinn (2006).

I obtained a reasonable set of O-levels but only showed talent in one area; mathematics. However, as I had obtained my A grade by sitting the exam in the May I was not allowed to take double maths at A-level like my classmates who had sat the exam in January, despite some of them only achieving a grade B. Working with numbers and general problem-solving were the only activities I enjoyed. Attending a maths taster event at Nottingham University around Easter of my lower sixth year resulted in my wanting to study nothing else. However, back at school my teachers said that, as I was only taking single maths, I was unsuitable to read maths at university even though I had obtained an A grade in the lower 6th exam Additional Mathematics. At the time, I failed to understand the personal devastation that this brought, and I did not think to discuss it with my parents or challenge the school's advice.

Unfortunately this still happens today. During my career, I have frequently come across schools (particularly independent schools) who deter able pupils from taking mathematics either at A-level (for fear they will not get straight A grades) or at university as it might lead to them attending a non-Russell group establishment. Few school teachers seem to understand the benefits that studying mathematics beyond GCSE can bring to one's career (House of Lords, 2012). Consequently, it is perhaps unsurprising that, as a country, we have one of the lowest uptakes of pupils studying mathematics beyond 16 (Lord and Lee, 2017).

Swayed by my teachers I opted to apply for a degree in Catering and Institutional Management although I had little interest in this as a career. At this point, all I wanted to do was get married and have children as I failed to perceive what else I could do. I had no idea what careers were available to me. My father was a senior civil servant; his work seemed to consist of attending meetings and reading and annotating government papers all weekend. I now realise that this was because he enjoyed his work, rather than because he was required to bring work home. Also, I realised too late that what looks boring and irrelevant to a 15-year-old can be surprisingly exciting just five or so years later. My lack of understanding of careers remained with me until after I began working in HE (4.4).

A significant factor affecting my choice of career, and indeed my attainment at school, was the fact that as a child and teenager I had a severely debilitating stammer. A career such as teaching that required public speaking seemed an impossibility, despite many childhood days being filled by running "school" for my dolls, making them suitably-sized exercise books and pencils and creating quite sophisticated lesson plans, although not understanding the implications of my actions. Despite attending weekly elocution lessons from the age of six, successfully taking many public speaking examinations between the ages of 9 and 17 and having speaking parts in many school plays, I still failed to realise that my dysfluency could be overcome in certain situations.

Having undertaken research in this area, I now understand how speech impediments can impact children's behaviour and self-esteem (Lindsay and Dockrell, 2000) and how, in turn, this can affect self-awareness and decision-making in adult life (Goodman, Joshi, Nasim and Tyler, 2015). However, the consequences are not all negative. Goodman et al. (2015, p.7) show how children, undergoing adverse difficulties resulting in producing their own coping strategies, frequently develop resilience and “the ability to summon strength when needed and ‘beat the odds’ of adversity”.

Passing only one A-level in Home Economics I then embarked on an HND in Catering and Institutional Management at the Polytechnic of North London (now London Metropolitan University) rather than a degree. Reflecting on this I believe that failing A-level maths was a consequence of my not being allowed to apply to study maths at university. Without mathematics, it seemed that my life had no meaning and I lost all motivation to succeed.

2.2 Early values

The first 18 years of my life instilled in me a sense that everyone should have equal opportunities despite their situation. I felt let down by an education system that required someone with a severe stammer to take a French oral examination whereas, for example, someone with an obvious physical disability, resulting in mobility issues, did not have to play hockey. At the age of 15 I could not see any difference between these situations. I foolishly did not think to discuss it with anyone, partly as discussions about anything, but especially something as sensitive as this, were incredibly painful and difficult.

This extended to my realising the importance that all people, regardless of age, gender, disability or social and racial background, should have the same opportunities. At the age of 18 I deliberately chose to go to an HE provider in a part of the country where I would have to mix with people from diverse backgrounds. This may sound unexceptional now, but to an only child from an affluent family attending an all-girls school in the heart of Surrey, these did not reflect the feelings or beliefs of my family or classmates.

I was keen to help those who were not as privileged as myself. I investigated the possibility of taking a gap year with an organisation such as Oxfam, but the application process was too daunting for someone who could not speak fluently. Instead, during my HND, I became involved in a local church and set about helping families from less privileged backgrounds than my own.

Alongside my desire to help others, were my feelings of self-doubt and lack of self-worth. Some of these stemmed from my insecurity around my adoption, whereas others came later and were largely due to my dysfluency which resulted in an inability to make friendships, feel valued and be “good enough”. Always compassionate when I saw others struggling I would want to help but too often did not know how. I still remember a teacher at Sunday School telling the class that a girl had left because no one spoke to her and that we had let her down. I felt mortified by this as I was in a similar position and I realised that I should have tried to talk to the other girl despite my stammer.

My continued attendance at such activities attests to my resilience which enabled me to keep going despite severe difficulties.

These experiences enabled me to see the necessity of supporting and helping students from all backgrounds transition successfully into a new environment when I was a first-year personal tutor and provided the impetus to start initiatives such as a peer mentoring scheme and the Maths Arcade (2.6 and 4.2).

2.3 Becoming a teacher

I married, against my parents' wishes, whilst studying for my HND in 1985. I graduated in 1987 and had four children between 1988 to 1997. We lived on a council estate in Brixton and, as my eldest approached the end of his primary schooling, realised that we did not want him to attend one of the ordinary state secondary schools in Lambeth. This led to my coaching him to pass entrance tests for local independent and grammar schools as we could not afford to pay a professional tutor like many of his classmates' parents. Consequently, I discovered that I could teach and that I still enjoyed solving mathematical problems and helping others to do the same. I went on to give all my children extra help with maths and English and enabled three of them obtain places in academically selective schools.

It was this experience that gave me an insight into education. At the time I had neither enjoyed my own education nor appreciated the good learning practices that had been instilled in me by my school, yet I now used them to find ways to teach my children.

It was clear I was someone who was intellectually capable, despite my school's best efforts to make me believe otherwise. I avidly read pedagogical literature to discover how children learned, and conducted experiments with my own children. I found that there appeared to be some truth in the theory of learning styles suggested by Barbe (1981) and Kolb (1984), despite several educators subsequently speaking out strongly against this (Willingham, Hughes, and Dobolyi, 2015). My eldest child seemed to be predominantly a kinaesthetic learner, in that he tended to prefer learning by physical experimentation rather than reading text. He struggled with wordy maths problems but with practise, and many football breaks, he became proficient.

2.4 Entering HE

Whilst teaching my children, I also initiated and ran several community projects on housing estates in Brixton. I used my networking and written communication skills to set up committees and successfully fundraise for money from organisations such as *Children in Need* and *Help a London Child*. On leaving Brixton and moving to Croydon in 2000, I started working in a pre-school, teaching early numeracy skills. I enjoyed this and, at long last, could finally see myself with a career. I completed an NVQ in childcare but realised that teaching Pre-School was too physically demanding for my back (I had had an operation to repair a slipped disk at the age of 20) so decided to put my efforts into something less physical.

In 2003 I started training to become an adult numeracy teacher. This was a mix of classroom-based learning coupled with work-based practise. Assignments reflected this, combining theoretical research with reflections on teaching practise and teacher observations. I excelled at the theory, which is where I was first introduced to the work of Kolb (1984). I now realise that this had a huge impact on my subsequent teaching and innovations (3.1.4, Chapter 4). My stammer was still an issue in some situations, but I could now speak in front of a small group of adult learners without too much hesitancy and embarrassment. At the end of my initial training period, my tutor suggested I think about obtaining a mathematics degree. I approached my nearest institution, The University of Greenwich. Not having passed A-level maths they suggested that I undertake their A-level equivalent maths test. I had two weeks in which to reconnect with calculus, logarithms and trigonometric identities; all topics that I had substantially forgotten. Amazingly, within this short time, I mastered more than enough to get over 80% on the test and so embarked on my HE journey in September 2004 as a new first-year undergraduate.

I thought I would bump along the bottom of the cohort, obtain a third-class degree and become a teacher in a Further Education (FE) college. I had no idea that I would already be better prepared than some of my cohort and, by the end of my degree, graduate with the highest mark that the Department had ever seen. Having taught adult learners myself, I understood that one of the difficulties is the “baggage” (described below) that they bring with them. I certainly had this in abundance which resulted in my having no confidence in my, seemingly hidden, ability.

There has been much research on the experiences of mature students in HE. Reay (2002) discusses the reasons that mature students give for entering HE, including the need to become someone and overcome the fear of shame that their previous failures have contributed to. Alongside this, she also acknowledges that the baggage that mature students often have includes grappling with feelings of worthlessness, a fear of losing their identity and a lack of family support. These fears are echoed by Baxter and Britton (2011) who discuss the risk brought about by change in personal circumstances. They also dwell on the advantages, such as mature students acknowledging that their studies empower them and help to make them more assertive and confident. Some of these positive characteristics have shaped the way that educationalists see adult learning (3.1.4). Many of these themes resonated with me and contributed to the motivation behind my public works. The experience of undertaking a degree as a mature student coloured my perceptions of HE and shaped my views on the student experience, teaching and learning, assessment and all aspects of undergraduate life.

2.5 HE from an undergraduate perspective

Although initially overawed by my place at university I soon realised that there was much that could be done to improve students' experience of HE both socially and academically. Despite the initial shock of returning to study after a gap of 20 years, halfway through the first term I had found my own pace and routine, and was surprised to see that I had much better time-management skills than my younger peers, many of whom seemed unable to attend lectures or complete coursework on time. I, on the other hand, attended all lectures, submitted coursework early whilst playing a large part in raising four, still reasonably young, children. I realise now that this attests much to my multi-tasking and juggling abilities that I had learned whilst bringing up a family and running several community projects. The concept of enhanced time-management skills in mature students is discussed in Trueman and Hartley (1996) who conducted research with psychology students at Keele. Richardson (2006), asserts that mature students display better study skills than younger students but acknowledges that this might be more to do with motivation coupled with students' upbringing and education than age. This is backed up by my own experience. I have seen mature students with a sound initial education, even if they had previously failed at school, possess good study skills whereas those with a poorer educational experience have continued to struggle in this area, despite having better motivation than their younger peers.

Being closer in age to my lecturers than most of my fellow students (there was only one other mature student of my age in my cohort), I learned quickly to see things from a lecturer's perspective, whilst experiencing, and thus understanding, the student view. This meant I was useful at explaining and clarifying university procedures to my younger peers and also putting their side to the academics in ways that the staff could understand. I resurrected the University Maths Society, MathSoc, and did much to promote activities where staff and students could meet informally outside of lectures. These mainly consisted of maths-related talks, some by outside speakers and some by students, as well as social activities often culminating in visiting one of Greenwich's local pubs. Perhaps I felt a need for "adult" company or maybe I genuinely realised students and staff would benefit from mixing with each other in a social context?

Reflecting on this I am still not sure of my motivations, but I know staff appreciated these events as did those students (about 10 of us) who were involved in the Maths Society and thus fully engaged in our programme of study. This was a diverse group of students in terms of age, ethnicity and other demographics. Our commonality was our motivation and general work ethic. At this point I did not understand students who neither attended nor seemed to want to get fully immersed in their education. I thought that if someone like myself with a young family could do it then everyone could and should. I failed to understand and see the difficulties that other students might be experiencing although I still helped these students when asked. By the end of my second year I knew my fellow students well. I was the student that others in my year came to for help with coursework. I set up some informal "help" sessions which many of my cohort attended; however, we could not get students from the year groups below us to attend, despite staff advertising them extensively.

Greenwich had (and still does have) a very diverse student body. According to the University's website (University of Greenwich, 2018) "Greenwich is one of the most socially diverse universities in the country. Only five others take a higher proportion of undergraduates from the four poorest groups." Half the student body is classified as being non-white and 52% are mature (over the age of 24) when they start their studies. Many students are the first in their family to attend university and so parents and other relatives have little understanding of what studying at university means. There are particular issues that affect working-class students and many of these are documented in the literature. Research by Reay, Crozier and Clayton (2010) provides a good resume of how working-class students from different types of institution view their studies and cope with students from more affluent backgrounds. Moreau and Leithwood (2006) discuss the problems associated with students needing to work to help support themselves and their families whilst they are studying and Leathwood and O'Connell (2003) suggest that students' grades would improve if they didn't have to work to earn money.

In my final year, I became a student representative for my year and pushed for several changes to assessments, such as clearer templates and word counts being published on time in order to help students manage the stressful final year workload. I worked hard to placate students when work was marked late and at the same time alerted staff to issues that were causing some anxiety. This was particularly crucial as one of these concerns coincided with the start of the National Student Survey (NSS), so my input enabled staff to catch the problem early before it affected the NSS result.

I realised the importance of a system for applying for Extenuating Circumstances (ECs) and even took advantage of it myself when suffering from acute anxiety due to the fear of looming exams in the first and final years (something that I had not coped well with as a teenager). However, despite my understanding of students' problems I did not see that I should make allowances where my work was concerned. When required to undertake a group project in my final year I refused to work with anyone except the two top students in the year. Amazingly this was tolerated (certainly not something I would allow any student to do). We worked well together, although I was annoyed that my mark was seemingly brought down by working with others (my view at the time). Despite my numerous protestations to the module leader and Head of Department no one gave me a satisfactory explanation as to why group work was necessary. Now, having attended many talks on the importance of group work, listened to employers and read relevant books and papers, I genuinely see the value of it and have gone out of my way to explain the numerous benefits of such assessments to students and other HE professionals. Challis (2015, p.86) describes the struggle of integrating group work fairly into the mathematics curriculum and cites the Confederation of British Industry (CBI) as stating the need for students to "know how to successfully function as part of a team". Other benefits include learning to collaborate as being key for undergraduate success (3.2.1). Challis (2015) goes on to discuss various ways that groups can be formed to prevent student angst. One of these is my own novel method of combining small, student-chosen, groups of three into groups of six so that students feel supported by being with some people they know and at the same time challenged by being with others that they do not know so well (Bradshaw, 2009; Rowlett, 2013). To help students understand the need for group work, and its long-term benefits, I have frequently brought back graduates, who had once been hostile to group work and then seen the benefit once in the workplace, to help current students realise its value.

2.6 Becoming a Professional

At the end of my final year I graduated with the highest first class mark the Department had ever seen and was offered a full bursary to stay and undertake a PhD in computing. I was also given the job of being first year personal tutor and lecturing three-quarters of the material in the first-year module Calculus and Mathematical Methods. My PhD supervisors were understandably concerned that this was too heavy a workload, but I was sure I could do it and foolishly (in retrospect) I convinced them to allow me to take it all on. I did not see how anything could be as hard as the final year of a degree and I felt I had a lot to offer first year students. I wanted to undertake the pastoral support more than the lecturing (speaking fluently was still far from guaranteed) as I found the thought of this very stressful. However, at that time, the then Head of Department would not allow staff to be a personal tutor if they did not have responsibility for teaching that year group.

My new teaching position at Greenwich coincided with an increase in student numbers for the Department of Mathematical Sciences. This was in part due to the outreach work I had been involved in as a student and in part due to the increasing reputation that existing staff had been working hard to create. As a result, I was given 50 personal tutees to look after in my first year of teaching. I was tasked, by the then Head of Department, with not losing any of them; a message I took very seriously indeed.

2.6.1 Improving transition to university

It was not long before I realised that one member of staff cannot devote enough time to 50 tutees plus have time for their own teaching and research. I needed help or a new strategy. Remembering that as a second-year undergraduate I would have had both the time and knowledge to help new first years settle in, I instigated a mentoring scheme that put new first year students into groups with a handpicked second year student as a mentor.

Looking back on my undergraduate days there were several things that I realised could be improved and I was now positioned to do something about them. As a new lecturer, I did not have the scepticism that longer serving members of staff sometimes have and, despite my age, I had the energy and enthusiasm to battle with university bureaucracy to see changes take place.

I was aware that one's initial perceptions of an institution can colour how well you engage with it and your learning. When I started as an undergraduate at Greenwich the first induction week could only be described as long and tedious. There was no fun, no excitement. The first day seemed very long and we were not even told where the toilets were or where to get food during the one-hour lunch break. The few activities seemed to have no point and we were given the same information multiple times. As a lecturer, I now understood the necessity of repeating information, but I could see that changes needed to be made to the first week activities in order to help students better engage and thus aid initial retention and attendance.

To this end I became part of the University New Arrivals Group and, with student input, planned and initiated several activities designed to gain the new mathematics students' interest and engagement. I was also aware of Ed Foster's work (Foster, Lawther, Keenan, Bates, Currant and Lefever, 2012) at Nottingham Trent on the importance of early friendships when starting university. Consequently, I made sure that the "Week One" activities encouraged friendship forming as well as imparting important information in a lively and fun way. I was influential in changing "Induction" to "Week One" and then "First Week". This was primarily due to overhearing a conversation between a group of sixteen-year olds starting at a local college saying that "Induction" weeks were a waste of time. If this was what school and college taught them then it was no wonder we were not getting students attending this crucial week. The change of name and our increased communication with new students about the start date brought a much higher percentage of new mathematics students in on the first day which has continued.

To help me improve the student journey, and put in place many of the enhancements that I wanted to, I enlisted the help of current students. I had developed an excellent rapport with many of the first cohort of students that I had taught. Several of them took on positions in the Maths Society during their first year as this had dwindled during my final year whilst I had been devoting more time to my studies. This group of students was instrumental in helping to run the mentoring scheme, plan and lead activities for new students and they even took on some of the organisation for the very first undergraduate mathematics conference, Tomorrow's Mathematicians Today (4.3). Without their help and support I would not have achieved the many things I have done in my career and would not have had such a meteoric rise to my current level.

2.6.2 Improving transition from university

Whilst I was aware that the activities I was arranging for students were helpful for them, as they provided different experiences and developed their confidence and communication skills, I did not understand the significance of this in terms of the graduate job market. It was only when this cohort of students was in their final year, and turned to me for careers advice, that I realised we were still failing students in this area (4.4).

Despite many of these students obtaining well-deserved first-class degrees, some of them, apart from those who had gone on to do an MSc elsewhere, struggled to secure a graduate-level job. I realised that there was more that we could do to help. I started working closely with the University's Employability and Careers Service (ECS) then called Guidance and Employability Team (GET) and co-ran sessions with them to help student mentors see the value of the mentoring scheme in terms of developing their transferable skills and how to use this to evidence these skills in job interviews.

I was aware that too many of our students did not know what they could do with a mathematics degree and there were very little University resources for them to use. It was obvious that as a Department we had to work on educating our students about the varied careers open to mathematicians and show them how to apply for these roles. I obtained funding from the National HE STEM Programme to run a project with the Adab Trust (a charity established to help improve graduate outcomes for students from BAME backgrounds) (Bradshaw, 2011a) to increase the understanding of both staff and students of issues connected to graduate employability (4.4.3).

As a result of listening to these talks, and others organised by GET, I increased my understanding of what more we needed to do to make our students more employable. I could see the value of the activities we had already run, and indeed graduates would come back and tell me that if it wasn't for the many opportunities that I had provided they would not have obtained their graduate-level jobs. However, I knew we needed to do more so it was not just the proactive students who were helped but that all students, provided they had some level of engagement with their programme, were able to benefit. It has been this desire, coupled with my motivation to help students achieve, that spurred me on to initiate and arrange the various employability activities I set up in the Department (4.4). It was these activities which propelled me into the role of Faculty Director Employability and contributed to my being elected as Vice President of the Institute of Mathematics and its Applications (IMA).

2.7 Summary

This chapter has provided an overview of my early educational and life experiences demonstrating how someone with one A-level and a severe stammer can become a senior university academic and manager and make a difference to the lives of many students.

The autoethnographic approach, along with critical self-reflection has helped me to demonstrate how someone from a well-educated background can still miss the point of education without appropriate parental support and good advice from teachers. Comparisons are made between my experience and the experience of first generation undergraduates whose parents do not understand the pressures and format of higher education. Alongside this, is research from the literature on how children who stammer can have low self-worth and suffer discrimination resulting in long term consequences affecting adult decision making. The positive side is that this can lead to individuals having increased resilience and perseverance. Dealing with discrimination and being marginalised at a young age shaped my beliefs and enabled me to put time and effort into helping all the students I encountered regardless of their background.

In examining my journey into HE and my time as a mature undergraduate, this chapter discusses issues such as the “baggage” that mature students are often encumbered with, issues affecting working class students and students from non-traditional backgrounds. It is my experience as an undergraduate that has enabled me to see some of the problems faced by students and so put in place suitable activities and projects designed to help both students and academics and thus improve the quality of the student experience for all. These activities started with improving induction week activities and introducing a peer-mentoring scheme for all new first year mathematics students. Concerned with helping students through difficult times I naturally gravitated to instigating curriculum improvements designed to ease transition. This is transition from school to HE, transition between different years of a degree programme and finally transition from HE to the workplace. The chapter discusses what it was about these times of transition that encouraged me to create my public works.

The combination of my undergraduate experience, my conviction that the student experience can be improved, and my values and personal experiences obtained before I entered Higher Education, has contributed to the creation of my public works described in Chapter 4 evidenced by a selection of journal papers and reports in the appendices.

3. Context

“*For the mind does not require filling like a bottle, but rather, like wood, it only requires kindling to create in it an impulse to think independently and an ardent desire for the truth*.” Plutarch (1927, p.259).

This chapter provides an overview of the HE landscape that I entered when I was appointed to my first academic position in 2007. It begins with a summary, obtained primarily from the literature, of why and how HE in the UK has expanded during the last 50 years, and outlines some of the key themes and metrics which institutions frequently focus on, in order to improve their position in national league tables. There is a section containing a summary of some of the learning theories which have underpinned my public works and another on the types and importance of discipline-based pedagogical research. I then combine the literature with my personal reflections and experiences in a layered autoethnographic style (Ellis, 2007), mainly using analytic autoethnography, to explain some of the problems that mathematics as a subject was, and is, facing, and then conclude by reflecting how these issues have affected the University of Greenwich and specifically the Department of Mathematical Sciences. I also discuss my career trajectory and the context in which I have been working. This background provides the context for my public works that are described in detail in Chapter 4.

3.1 Ideological, Cultural and Political Environment

Over the last 50 years the UK has experienced an enormous increase in the number of students obtaining first degrees from universities (Universities UK, 2016b; Office for National Statistics, 2018). This widening of participation in HE is partly due to the proliferation of universities including the creation of about 40 new universities (many previously being polytechnics) as a response to the *Further and Higher Education Act* (1992). However there have also been substantial changes to university funding and a shift in society’s perception of universities being for educating the masses as opposed to just the elite (Underdal, 2010).

The Dearing Report (The National Committee of Inquiry into Higher Education, 1997) suggests that back in 1961 about 5% of the UK’s under 21 population embarked on an undergraduate degree at university. In 1980, around the time I was thinking of first applying to university, this had risen to 15% (Bolton, 2014). This level remained reasonably stable until 1992 when the numbers of UK HE entrants doubled due to government legislation that enabled former polytechnics to become universities (Scott, 1995). By 2000, just before I entered HE for the second time, this participation had risen to about 33% (The National Committee of Inquiry into Higher Education, 1997).

According to Scott (1995, p.23) this growth was not just down to the creation of new Higher Education Institutions (HEIs) and different funding strategies, but to a fundamental change in society partly led by Tony Blair's New Labour government which embraced higher education for all parts of the community setting a goal of 50% participation which, according to Augar (2019) has now been reached. This became known as the widening participation agenda (Kettley, 2007). With this expansion of the HE sector came the decision by governments to charge fees to meet the increased cost of Higher Education. Much of the reasoning behind this is detailed in Bunce, Baird and Jones (2016) where the effect of charging on the student is discussed. There is some evidence that this advent, and then subsequent increase, in student fees cause students to see themselves as consumers paying for a service (Bunce et al., 2016) and further research (Temple, Callender, Grove and Kersh, 2014; Beneito, Bosca and Ferri, 2018) that examines how this affects students' expectations and academic performance (3.1.3). There is also concern that tuition fees have deterred some groups of students, particularly mature students, from applying (MillionPlus, 2018), with Augar (2019) commenting that students from disadvantaged backgrounds are more likely to be debt-averse and so high tuition fees are more likely to be a deterrent to this group. These changes in government policy have resulted in increased competition amongst HEIs and new metrics being introduced to measure their performance, forcing many HEIs to focus resources on increasing their performance on retention, employability and the students' experience (Longden, 2012).

This consumer-driven society has resulted in some students seeing their learning as being the university's and lecturers' responsibility rather than their own (Wong and Chiu, 2019). This attitude can make it hard for lecturers when they invest time and effort into creating thought-provoking lectures and assessments, and then find that students do not attend class or complain that they are not being taught everything they need to know to complete an assignment (Bunce et al., 2016). It may also cause some staff and institutions to shy away from setting assignments designed to make students think through problems for themselves, for fear of generating more complaints (Wong and Chiu, 2019). This is summed up by the words of one academic from the 2017 THE Teaching Survey: "many universities have shifted their focus towards student satisfaction at the expense of academic quality" (Grove, 2017).

If it hadn't been for the move towards widening participation (3.1) I do not think I would have considered entering HE to study for a degree. The expansion of places available meant that Greenwich offered entrance tests for students like me with non-traditional entry qualifications. As an academic I modified the tests and used them on numerous occasions to admit students who would not otherwise have been able to gain entry to HE. However, despite widening participation, if, in 2004, tuition fees had been at the level they are now I would not have applied to enter HE as the thought of such a large loan and ensuing debt would have seemed too great a hurdle.

3.1.1 Student experience

This growth in the number of university places, has led to increased competition between HEIs as there are now more places available than potential students (Universities UK, 2018). At some universities, this has culminated in a reduction of the entry requirements to attract more students (Universities UK, 2018). This competition has fuelled university marketing campaigns: neighbouring institutions claim to give students a better experience than their competitors which has translated into university staff being put under pressure to do all that they can to improve the following areas (Bunce, 2016).

a) Retention

   Many universities put a high emphasis on increasing student success measured by the number of students completing their higher education programmes. Some cite retention issues as being the result of widening participation and the subsequent increase in student numbers (Wright, 1996) (3.1). Indeed, a government report on student retention (Select Committee on Education and Employment, 2001) links the 'gentle rise' in non-completion rates with the policy of taking 'risks' in the admissions process and thus implying a lowering of standards. However, some of the research in this area (Thomas, 2002) suggests that the emphasis should be on institutions to offer appropriate support to students rather than blaming the students' lack of preparedness (3.2.2). Many studies have researched the issues which influence success and retention (Thomas, 2002 and Wood and Beyer, 2017). These include but are not restricted to: preparedness for academic study, academic experience, institutional support and expectations, social inclusion, students' finances and family support and situation (Thomas, 2002). The acknowledgement of these and other factors have led many institutions to instigate innovative interventions designed to help students settle in and engage more effectively with the institution and their academic study. The Maths Arcade is one such intervention designed to aid student transition and thus increase retention (4.2). More on retention, specific to mathematics, can be found in section 3.2.2.

b) Employability

   The advent of increased tuition fees and student loans has done much to concentrate prospective students' minds on the value of a degree and the increased chances of them obtaining a higher-paid job at the end of their studies (Bunce et al., 2016; Waldock and Hibberd, 2015). This is therefore also important to HEIs who are trying to attract prospective students to their institutions. According to Yorke and Knight (2006, p.2) "employability refers to the potential a graduate has for obtaining, and succeeding in, graduate-level positions". Employability is one of the measures used in various HE metrics (3.1.3) and is thus gaining more importance across all HEIs. Another Higher Education Academy (HEA) report states that nowadays "Higher education providers are under considerable pressure from policymakers, students and employers to ensure that graduates emerge from higher education ready for the labour market" (Artess, Hooley and Mellors-Bourne, 2017, p.6). The HEA have developed an employability community of practice to enable practitioners share good practice in this area and a framework (HEA, 2015) designed to help HEIs review their employability provision and develop its own approach.

Much has been written on the relationship between employability and Higher Education (Johnston, 2003). According to Harvey (2000) some academics fear that pushing employability is an anti-intellectualisation of academia whereas others see employability as an important part of transformative lifelong learning. Academics are understandably concerned that HE should not be "downgraded" to "training graduates for jobs rather than improving their minds" (Harvey, 2000, p.3). Moreau and Leithwood (2006) show that students from post-1992 universities are disadvantaged when it comes to the graduate job race. This is exacerbated further when the graduate is female, from a BAME background and/or a lower social class. Many authors on the subject talk about social capital and how providing networking events, mentors and other contacts in industry can greatly help the students from these disadvantaged categories (Batistic and Tymon, 2017). These were the issues that I sought to address with my various employability initiatives. Placements give students a distinct advantage but, as the application process is just as competitive (if not more so in some cases) as the graduate job market (Moreau and Leithwood, 2006; Waldock and Hibberd, 2015), those students without the necessary social skills to succeed at interviews are once again at a disadvantage.

c) Student engagement

The term "student engagement" is frequently overused in higher education. It originated from research on student involvement by Alexander Astin in the 1980s (Astin, 1984). As with retention and employability, a large body of research exists around student engagement (Ashwin and McVitty, 2015). A literature review, conducted by Trowler (2010, p.3), defines Student Engagement as being "concerned with the interaction between the time, effort and other relevant resources invested by both students and their institutions intended to optimise the student experience and enhance the learning outcomes and development of students and the performance and reputation of the institution." A student who is more engaged in their programme of study is arguably more likely to be successful and have a positive graduate outcome (Trowler, 2010). Thus, student engagement is considered vital for universities, and staff at many institutions are encouraged to put time and energy into new projects and teaching methods that are seen to be instrumental in increasing this. My works have all been designed with the goal of increasing student engagement and improving the student experience.

3.1.2 School curriculum changes

It is not only government policy that affects the numbers of students entering UK universities each year. Changes to UK school curricula and public examinations can also have influential consequences (Abramsky, Porkess, McColl and Sangwin, 2001). In some subjects, a small change to the A-level syllabus can have a large impact on the numbers of students taking the subject at A-level and then pursuing it further at university (Porkess, 2001).

A-levels were first introduced in the 1950s (Bolton, 2012). Since their introduction, there have been concerns that the post-16 curriculum has narrowed too much, compared to that of other European countries (Sutch, Zanini and Benton, 2015). In the 1980s, the then government sought to address this concern with the introduction of AS (Advanced Subsidiary) levels (Bolton, 2012). The purpose of these was to enable students to study a further one or two subjects alongside their A-levels with science-focussed students being encouraged to take English AS and arts-focussed students to take Mathematics AS (Sutch et al., 2015). However, Sutch et al. go on to explain that the initial uptake of these new qualifications was very low and there was a concern that they were not being used as envisaged. Instead schools were choosing to enter candidates for the AS in subjects where they were not sure they would pass the A-level or choosing to use the AS as an introduction to the subject (Broom, 1989). There was also concern and a lack of understanding by university admissions tutors about the level of study reached in an AS qualification (Evans, 1990) with many universities stipulating that they wanted candidates with three full A-levels rather than two A-levels and two AS-levels, as per the government's original proposed plan (Sutch et al., 2015). In 1995 Sir Ron Dearing was commissioned to review post-16 education and qualifications in the light of concerns over AS-levels and the parity between academic and vocational qualifications. His ensuing report (The National Committee of Inquiry into Higher Education, 1997) contained various proposals, many of which were subsequently implemented in the Curriculum 2000 framework (Sutch et al., 2015).

Curriculum 2000 (3.2.2) standardised the procedures for A-levels and AS examinations, with students being required to take three AS modules for each subject studied in the first year after

GCSEs and then, if they wished, they could continue to study that subject for a second year taking a further three A2 modules to get the full A-level (Baird, Ebner and Pinot de Moira, 2003). This shake-up of A-levels produced major unforeseen implications for university entrants (Sutch et al., 2015). There were many other issues that Sutch et al. (2015) summarise. These include the fact that initially the workload, both for students and those responsible for timetabling such a large number of examinations, was unworkable. This led to a reduction of the number of modules in each A-level from six to four in most subjects. According to Cadwallader and Tremain (2013), citing the Tomlinson inquiry (Tomlinson, 2002), the changes had been rushed through, resulting in teachers not having adequate time to prepare pupils or material; Sutch et al. (2015) comment that the emphasis on assessment meant that pupils did not get time to look at anything outside the curriculum and that the new system made it very hard for schools to plan, as they did not know until just before the start of term how many students would be taking each subject to A2; also the rules around resits and certification of qualifications were complicated with different universities giving conflicting advice on the inclusion of AS grades on application forms. There were also issues with standards, as awarding bodies, examiners and teachers held conflicting views. Some subjects, such as Mathematics, had other more specific problems with the changes which are discussed later in this chapter (Abramsky et al., 2001; Sutch et al., 2015) (3.2.2).

3.1.3 HE Metrics

The Higher and Further Education Act (1992) required universities and other education providers to submit data on specific activities to the UK HE funding councils (HESA, 2018b). This led to the establishment of the Higher Education Statistics Agency (HESA) in 1993 (HESA, 2018c). The data collected by HESA is widely used in many league tables such as *The Complete University Guide*, *The Times* and *Sunday Times Good University Guide* and the *Guardian University Guide*. These league tables form part of the information that is available to prospective students and their parents when choosing which course and institution to apply to (Turnbull, 2018). However, despite the original data being of good quality, the various league tables are compiled using different methodologies, which sometimes vary year on year, so that the same university can appear in quite different places in the different tables. Turnbull (2018) explains the differences in the methodologies but goes on to state that the wide range of HEIs in the UK mean that the league tables are in many ways comparing apples with oranges and pears and, as such, do not enable the rich diversity of UK higher education to be appreciated. As well as the data being used to inform various league tables, the 2011 white paper: *Students at the Heart of the System* (Department for Business Innovation and Skills, 2011), required universities to put frequently requested data on the website to enable prospective students and their parents to make comparisons between degree programmes. These Key

Information Sets (KIS) include information taken from the National Student Survey (NSS) data returned to HESA, the cost for students including accommodation and available financial support, employment statistics from the Destination of Leavers of Higher Education Survey (DLHE) and information about the students' union. The NSS is taken by all final year undergraduate students. It includes questions on a range of topics such as teaching, assessment and feedback, and academic support. The DLHE survey currently (2017) measures graduate destinations 6 months after graduation. However, a new metric to measure graduate outcomes 15 months after graduation will be introduced from December 2018 (HESA, 2018d). As well as being available on an individual institution's website the KIS information is readily accessible via the, government-run, Unistats website (Office for Students, 2018).

More recently the government has put in place the Teaching Excellence Framework (TEF). This originated in the Conservative 2015 election manifesto and was then fleshed out in the government's green paper (Department for Business, Innovation and Skills, 2015) and subsequent white paper (Department for Business, Innovation and Skills, 2016). The TEF was initially introduced at institution level and is currently (2018) being rolled out at subject level. It is designed to provide clear information to students on the teaching quality of institutions, send powerful signals to prospective students and their future employers and thus inform the competitive market (Department for Business, Innovation and Skills, 2016).

Spence (2019) argues that this emphasis on performing well in league tables, in the light of increased competition amongst HEIs, may harm rather than improve the student experience as academics will be less willing to take risks and innovate. Muller (2018) explains how using simple measures for complex problems is often flawed and a metric-led approach to quantify performance often misses the point of what they are supposed to measure. On a similar theme it is worth noting that, in 1868, when the rate of patient mortality was proposed as the metric to measure nursing performance, Florence Nightingale explained that as the best trained nurses looked after the patients most likely to die, it was inappropriate to use this to quntify the efficiency of nursing (Bradshaw, 2017b; E3). Although it has been said that my works have contributed to high rankings for Mathematics at the University of Greenwich in various league tables this was not the primary motivation (Bradshaw, 2017a; A1).

3.1.4 Learning and Teaching in Higher Education

The introduction of the TEF arguably focuses the spotlight on a university's teaching methods (Universities UK, 2019; Spence, 2019). Whilst there is a push for universities to increase the proportion of staff with suitable teaching qualifications, academics are expected to develop excellence in so many areas that often the theories underpinning students' learning and impact on teaching are overlooked (Fry, Ketteridge, Marshall, 2009). There is also some debate about whether adult learning differs in character to that of children (Fry et al., 2009). Knowles et al. (1984) consider that there are five principles which result in adult learners requiring different learning theories to children (2.4). These are:

- The maturity of the individual leading to an ability to self-direct their learning.
- More life experiences which can be a rich resource for learning.
- A need to know something which increases their drive for learning.
- Adults tend to be less subject-centred and more problem-centred.
- Adults most potent motivators are internal.

I certainly identified with much of this personally when undertaking my degree at Greenwich and consequently encouraged a mature approach in my students so that they could learn how to self-direct their learning. I prioritised getting to know students so that those with useful life experiences could be encouraged to make use of them or share them with others. I emphasised the need for students to learn by setting work in the context of future employment and tried to instil motivation. These principals are also relevant to learning other skills such as general research or employability skills and this is discussed further in conjunction with my individual public works (Chapter 4).

When entering HE I was already aware of some of the learning theories relevant to adult learners, having studied this recently as part of my adult numeracy qualification. Reflecting on this now, I remember rereading some of my notes at the start of my degree, although, by the end of the first year, this had been largely forgotten due to the pressures of concentrating on learning mathematics. However, when I graduated and started lecturing I transferred my notes on these theories to my office and referred to them frequently (2.3, 2.4). Indeed, my Head of Department commented that I was the only mathematics lecturer he knew with Kolb's Learning Cycle (Kolb and Fry, 1974) stuck on the wall.

Kolb's Theory of Experiential Learning drew on the work of Dewey, Lewin and Piaget (Kolb, 1984) and according to Fry et al., 2009, p.15) is "based on the notion that understanding is not a fixed or unchangeable element of thought and that experiences can contribute to its forming and re-forming. Experiential learning is a continuous process and implies that we all bring to learning situations our own knowledge, ideas, beliefs and practices at different levels of elaboration that should in turn be amended or shaped by the experience – if we learn from it." As time went on I no longer referred to the notes but my knowledge of Kolb, in particular, stuck with me and now, as I reflect on this, I realise that this has greatly impacted the works I have created (Chapter 4).

3.2 Discipline and academic literature

The word mathematics is derived from the Greek word μάθημα (mathema) meaning knowledge, study, learning (Kyle, 2015). Too often today, mathematics is thought to be about manipulating numbers using algebra and arithmetic, but it is important to understand that it encompasses much more than this. Mathematics has originated from, but is not restricted to, the study of number, space, time and motion. Every civilisation has constructed ways to count and define numbers and many have been fascinated by the stars and calendar. The earliest evidence of counting is thought to be a tally stick (or rather bone) originating from 9000-6500BC in present-day Zaire. Current thinking is that this is likely to represent the tallying of lunar phases (Fauvel and Grey, 1987). The earliest recordings of algebra are from Babylonian times, about 2000BC (Courant and Robbins, 1996) but there is much more evidence of recorded mathematics from the ancient Greeks circa 600BC (Katz, 2004) with Euclid's Elements originating from about 300BC.

Until more recent years, mathematics was predominantly thought to be "science of number and magnitude" (Boyer, 1968, p.1). From the nineteenth century, with the development of calculus and the introduction of the concept of a limit, it became more about logical purity and abstraction (Courant and Robins, 1996). Indeed, Cheng (2018, p.9) defines mathematics as the "logical study of how logical things work." It is interesting that mathematics appears to be the only academic subject for which there appears to be no agreed definition (Kyle, 2015). A recent Twitter poll that I conducted on the subject produced the following definitions:

> "I call it the science of patterns. And the art of solving problems" (@tiniesandminies, 2018).
> "The study of the basic language of the universe" (@Heimday, 2018).
> "Spotting patterns *is* mathematics, it may not be arithmetic or algebra" (@jimalkhalili, 2017).
> "Math is the only thing which is truly universal; it underlies and makes it possible to understand and communicate with everything" (@SRavn, 2012).
> "Study of rules (tautologies) with inherent logic, & their applications, in > 1, 200 sub-fields including arithmetic, numbers, geometry etc" (@stoiczak, 2017).

Older definitions, as mentioned in Kyle (2015, p.1), include:

> "Thus mathematics may be defined as the subject in which we never know what we are talking about, nor whether what we are saying is true" (Russell, 1917, ch4)
> "Mathematics is the science which draws necessary conclusions" (Pierce, 1882, p.1).

Many popular writers of mathematics, including Frenkel (2013) and Stewart (2006), have also sought to define the subject but, given the enormous reach of mathematics as described above, it is very difficult to do this effectively. The purpose of this discussion is to emphasise the very broad range of areas that are encompassed by the discipline and to highlight the fact that mathematicians themselves do not have an agreed definition. This matters because this is one of the sources of confusion for new university students (Kyle, 2015). Probably the only thing mathematicians can agree on is that mathematics at university is vastly different from mathematics at school, and this poses a problem for universities; on the one hand, how to make it attractive to new prospective mathematicians and, on the other, how to retain those who have chosen to study it and may have discovered that the subject is not what they expected (Croft and Grove, 2015).

It is also important to make mention of the UK public's apparent misconceptions and general dislike of the subject. It is not unusual to get a negative reaction when introduced to someone for the first time as a mathematician or maths teacher. Their response often includes an account of how much the person hated the subject or their teacher at school. Ernest (1996) describes people's perceptions of mathematics as being "difficult, cold, abstract, and in many cultures, largely masculine" (Ernest, 1996, p.802). This negative perception that mathematics is hard and that most people struggle with it means that parents often pass these negative feelings on to their children. Primary school teachers, who have little confidence in the subject, can unwittingly convey their angst to their pupils (Ramirez, Hooper, Kersting, Ferguson, Yeager and 2018; Vorderman, Budd, Dunne, Rahman-Hart and Porkess, 2011). Even secondary school maths teachers, who found the subject hard at university, can make negative comments to their students thus deterring them from taking it to A-level or degree level (Tschannenn-Moran and Hoy, 2001).

I have sought to challenge these negative views by arranging and speaking at various events designed to show the audiences that maths is fun. These have consisted of talks to school children aged 7-18. Talks and masterclasses at universities and talks to the general public and school children about the mathematics and statistics undertaken by Florence Nightingale as she campaigned for the reform of British military hospitals. I am also a tutor on the online Citizen Maths course (Citizen Maths, 2014) which was designed to help improve the mathematical skills of non-mathematicians. This involved my giving several radio interviews discussing public perceptions. The longest of these was on Tim Harford's *More or Less* programme on BBC Radio 4 (More or Less, 2017).

3.2.1 Mathematics at University

Given the problems that one has in providing a definition of the subject it is obvious that this poses a problem for universities when trying to attract new undergraduates (Kyle, 2015). It is impossible to even touch on all the main areas of mathematics in an undergraduate syllabus, so university mathematics curricula vary widely, often depending on the research interests of current teaching staff. A list of the main sub-fields of mathematics can be found in Deloitte (2012).

The HEA subject benchmark (HEA, 2015) states that calculus and linear algebra must be included in all undergraduate programmes. Apart from these, universities can decide what else to offer. This is discussed in detail by Robinson, Challis and Thomlinson (2010a) and can include areas of statistics, management science, computing, or mathematical physics as well as more abstract pure mathematics. Robinson, Challis and Thomlinson (2010b) describe the differences between institutions offering mathematics degrees; research-intensive Russell Group institutions tend to offer more pure mathematics modules such as group theory, topology and knot theory, and have a focus on helping able students obtain research positions after graduation. They can afford to teach smaller groups and often have a larger pool of PhD students to help with marking and taking tutorials. They can also offer more specialist applied mathematics modules such as celestial mechanics, mathematical acoustics or quantum mechanics depending on staff expertise (Maths Careers, 2019). The names of many of these modules mean little to the prospective undergraduate choosing to study mathematics at university but a wide variety of interesting-sounding topics can make them think that at least there are plenty of alternatives available if they do not find a particular module amenable. Post-92 university mathematics departments tend to offer more practical modules such as statistics, operational research, programming and financial mathematics. This is partly because these areas are thought to appeal to a wider group of undergraduates and so can be taught to larger groups thus reducing costs (Robinson et al., 2010a). These subjects also cover the skills and knowledge that employers reportedly require (Challis et al., 2009). However, this does not mean that these subjects are not taught in research-intensive institutions as well.

It is not only the curricula that varies from university to university but also methods of teaching and assessment (Alcock, 2013). Some universities favour a less-interactive "chalk and talk" style while others try to make their teaching more interactive to increase students' engagement in the material (Abdulwahed, Jaworski and Crawford, 2012). Mathematics is not something that can be learned by rote but needs hands-on practice in order to learn how to think mathematically to solve problems (Devlin, 2012). A student comments, "mathematics is much more than factual recall and opinionated writing, mathematics is something different; it is a way of thinking, a skill, an art in the true sense of the word" (Wakeley, 2004, p.8).

The theories underpinning the learning and teaching of mathematical thinking and problem solving is a large research area where there are numerous viewpoints. Some educationalists assert that

Constructivism is the key to successful learning of mathematics (Sriraman and English, 2010). Constructivism perceives learning as a process of constructing knowledge by individuals themselves as opposed to the passive teacher-student model (Abdulwahed, Jaworski and Crawford, 2012). My main inspiration has been the work of Polya and other maths educationalists such as Mason (1982) and Tall (2004) who embrace Polya's work. Polya's theories developed from Constructivism (Abdulwahed, Jaworski and Crawford, 2012), the key attribute being that mathematics is learned actively and it is where one is stuck that the most learning takes place. My knowledge of Polya and Mason's works was one of the motivations behind the introduction of the Maths Arcade and screencasts to promote thinking skills in problem solving. Pritchard (2015, p.59) discusses how the way mathematics is taught in school can contribute to new university students not being ready for taking "individual responsibility for learning and sustained attention to problems" which is necessary for success in learning mathematics at university. At school level, recent research has shown that working on improving children's mathematical mindsets, building on Boaler's (2016) theories, has significant impact on their ability to problem solve (Daly, Bourgaize, Vernitski, 2019).

Confidence is also key to learning mathematics (Dweck and Molden, 2005). Lawson (2015) notes that mathematics undergraduates have often been the best, or one of the best, in mathematics at their school. They then find that this is not the case at university and lose motivation rather than put in more hours in order to practise and master the new skills that they need. Anthony (2010, p.9) found that "successful students placed more importance than failing students on … understanding rather than rote learning, and the ability to work independently." Walker (2015, p.72) discusses ways of helping students develop the necessary skills and mindsets to enable them become independent learners and problem solvers focusing on "motivation, autonomy and collaboration" and Williams (2015, p.35) concludes his discussion on the transition of mathematics students by saying: "Students in transition would benefit from more preparation or even information concerning the change in learning systems to be expected when they arrive at university: what lectures are for, how to manage lectures, how to work around the system to get the support they may need, and the importance of making social contacts and informal support networks." The importance of making social contacts and informal support networks are fundamental to the Maths Arcade initiative (4.2).

At the time of writing (2018), there are 75 university departments offering mathematics degrees in the UK. According to HESA (2018a) the 2016/17 intake had a total of 9,120 (3,355 female and 5,760 male) new undergraduates studying mathematical sciences out of 424,565 new undergraduates in all subjects (236,625 female and 187,815 male).

Although the number of pupils taking A-level Mathematics and Further Mathematics has risen in recent years (Stripp, 2017), the recent changes to the A-level mathematics curriculum are giving university mathematics admissions tutors cause for concern (Lee, Lord, Dudzic and Stripp, 2018). According to a report by Mathematics Education and Industry (MEI) there has been a reduction in the uptake of AS/A level Mathematics 2017/18 compared to 2016/17 but the extent of this reduction will not be fully known until summer 2019 when the final exam results are published (Lee et al., 2018). Concern over student numbers is not new. These and other concerns, particular to mathematics, are discussed in section 3.2.2.

University mathematics is usually taught through lectures followed by tutorials or exercise classes where the recently taught material can be practised (Alcock, 2013). Nowadays many lecturers use a whiteboard or visualiser rather than a blackboard and augment this with online notes. Mathematics is a subject where lecturers need to write in class to show how a proof develops or to give an example of solving a problem (Devlin, 2012). Partly due to the widening participation agenda (3.1), and the increased numbers of students from a diverse ability range and background, it is becoming more necessary to find new ways to engage learners, as the traditional methods can alienate those who have not been schooled in this way and are less adaptable to change (Pritchard, 2015) (3.2.2).

In July 2017, at a workshop to commemorate the life of Professor John Blake (3.2.3) the future of HE mathematics was discussed. Amongst other suggestions was a call to overhaul the mathematics curriculum in response to new requirements from industry (Grove and Kyle, 2018). Other suggestions made at that event are discussed in section 5.3. I recently (2019) spoke at the HoDoMS conference on employability. I reminded Heads of the call to overhaul the curriculum and urged them to respond to the recommendations coming out of this workshop (3.2.3, 5.3).

3.2.2 Issues affecting mathematics at university

The Mathematics Problem

In 1995 the London Mathematical Society (LMS) convened a group to look at the problems encountered by university mathematics departments in teaching underprepared undergraduate mathematicians. It was felt that these problems stemmed from changes to school curricula that had been put in place without consultation with those teaching in HE. The Institute of Mathematics and its Applications (IMA) and the Royal Statistical Society (RSS) accepted invitations to participate in the group. The group's findings and recommendations were published in a report *Tackling the Mathematics Problem* (London Mathematical Society, 1995). The report stated that the problems included a serious lack of essential technical skills, a marked decline in analytical powers when faced with simple problems and a changed perception of what mathematics is, in terms of precision and proof. Amongst other things, it called for government action in several areas; including setting up a standing committee to provide an overview of mathematics education from primary school to HE and overhauling the mathematics curriculum from ages 5-16 and 16-19.

After this came several responses, some in the form of potential solutions. One of these, *Measuring the Mathematics Problem* (Savage and Hawkes, 2000), recommended that all mathematics-based degree courses should have a diagnostic mathematics test for entrants and that support should be given to those students not performing adequately on the tests. It also echoed the call for the formation of a standing committee on mathematics education.

Curriculum 2000

Curriculum 2000s reform of A-level examinations in England (3.1.2) hit mathematics particularly hard (Kyle, 2015). Students were now expected to take four or five AS levels in year 12 and so did not have as much time to devote to mathematics. This, coupled with particularly poor AS mathematics results in 2001, due to problems with students transitioning from GCSE to AS, led to a reduction in the number of those taking mathematics to A2. Numbers fell from 65,891 in 2001 to 53,940 in 2002 (MEI, 2015). The impact of this on HEIs was that many establishments received fewer applications and consequently a smaller intake, which resulted in some HEIs, like Hull, ceasing to provide mathematics degrees completely (Steele, 2007). Similar problems were noticed by other Departments, such as engineering and physics, who relied heavily on recruiting students with A-level mathematics (Kyle, 2015).

Transition

As mentioned, the gap between mathematics at A-level and university mathematics is one that many students find difficult to cope with and some fail to acclimatise to a new curriculum and different study methods (Croft and Grove, 2015). The variety of universities offering degree-level mathematics means that expectations, as well as curricula, are very different (Maths Careers, 2019). Some Departments expect students to have perfect knowledge of all A-level mathematics and further mathematics material whilst others provide a refresher course, online refresher material or a slower start to the first year recapping some A-level material during the year. Prospective students do not appreciate these differences and tend to choose institutions on other factors such as facilities, league table position and location (Robinson et al., 2010a). This can result in a mismatch between the student’s and the lecturer’s expectations which makes the transition for the student even harder. Retention (3.1.1) is an issue for Mathematics Departments. Some universities accept that a certain level of attrition is only to be expected during the first year whereas for others, especially post-92 institutions, numbers are critical for the Department’s survival, so they are keener to help students transition successfully in order to maintain numbers and thus fee income (Mccaig, 2015). Transition from school to university is such a serious issue for mathematics students that many academics, including myself, have dedicated research projects to this. Key elements of this research and current thinking is documented by Khan and Kyle (2002) and Grove, Croft, Kyle and Lawson (2015).

Employability in the curriculum

As discussed in section 3.1.1, student employability and graduate outcomes are important measures for HEIs (Waldock and Hibberd, 2015). As a result, every university department is under pressure from senior university managers to maximise these measures. However, the curriculum of many traditional mathematics programmes is designed to prepare students for research rather than non-academic employment (Waldock and Hibberd, 2015). Waldock and Hibberd (2015) go on to point out that this needs to change as many students now choose to study mathematics to boost their career prospects. Mathematics degrees open the door to many different and varied careers (Maths Careers, 2019). Challis, Gretton, Huston and Neill (2002) acknowledge that mathematics graduates can go on to be scientists, engineers, economists, actuaries, researchers, teachers or go into general employment. They say that the transferable skills needed alongside their mathematics knowledge include communication skills, working with others, interpersonal and leadership skills. They advocate that these skills are taught and practised in the mathematics curriculum through including group work at all levels and a range of assessment methods to incorporate different writing styles and technology.

This is not only being driven by the government's employability agenda; the subject benchmark statement for mathematics, statistics and OR (QAA, 2015) also acknowledges the importance of developing generic skills. Many staff would argue that it is not the job of university academics to fill the gaps left by schools and parents but, given the increasingly diverse student body (particularly in post-92 institutions), the onus is on academic staff to plug the gap if they want to improve their DLHE scores and thus impact league tables (Hibberd and Grove, 2009).

Staff at in the Mathematics Department at Sheffield Hallam point out that some professional competencies "such as logical and abstract thinking, and an analytical approach to problem solving" are inherently built into a mathematics degree but their research showed that even before the increase in tuition fees, students had chosen to study mathematics to increase their chances of obtaining a good graduate-level job (Challis et al., 2009, p.38). Coupled with this was research from Prospects that showed only 2.1% of mathematics graduates were going into the engineering or scientific research areas that previously mathematics degrees had been geared towards (Challis et al., 2009; Prospects, 2018). Employers were becoming more vociferous in their comments on the general skills required by graduates. However, despite mathematics students seeming to understand the need for good communication skills in their working life (Challis et al., 2009), they are often loath to devote curriculum time to this. For example, many mathematics academics can recount numerous stories of students complaining about report writing. When I first introduced a book review assignment into a first-year module, students complained that they did not do a maths degree to spend their time reading. However, these same students learned to appreciate this assignment as they realised the books were interesting and they understood the need to be able to write for different audiences (Bradshaw and Richardson, 2013).

Challis et al. (2009) pose four questions at the end of their paper:

1. "Is it desirable to have a separate skills module, or to integrate skills development into other activities in the course, or some combination of these?
2. How can skills such as writing, presenting, and working with others be developed through mathematical activities, for example through modelling or project work, or indeed through mathematical modules?
3. Could a learning log have a role to play in encouraging a reflective approach?
4. If skills are to be assessed, what part should that assessment play in the overall pattern of assessment?"

I have sought to answer these questions for students at Greenwich and I have used them to provoke discussion in University-wide workshops at Greenwich and sector-wide STEM conferences (Bradshaw, 2016a; C5).

Hibberd and Grove (2009) discuss a study, funded by the HEA, that investigates the skills that employers require. The research, commissioned by the Centre for Education and Industry (CEI) at the University of Warwick, consulted employers from five different companies who frequently employed mathematics graduates. The results showed that, although mathematical and statistical skills are important to these employers, engineering and physics graduates often possess the same skills. They conclude by saying that "the findings from the study indicate employers are becoming increasingly reliant upon graduates having particular sets of competencies as well as academic qualifications" (Hibberd and Grove, 2009, p.34). The paper goes on to discuss various projects seeking to address these generic skills within the curriculum. These include:

- Group projects designed to get students working with each other on mathematical modelling exercises;

- Promoting opportunities for maths students to undertake a sandwich placement or a work-based learning placement in school or industry;
- Encouraging students to take part in university employability awards and events;
- Incorporating informal student presentations into lectures;
- An increased emphasis on personal development planning (PDP) either through reflective journals in a variety of modules or through specific stand-alone skills modules.

When I started at Greenwich all of this was already taking place and yet, as a student, I felt that the Department had done nothing to help my employability (2.6.2). I realise now that it was because the value of these activities was not made explicit. We had no input on the types of careers that mathematics students could undertake, or the skills employers wanted, so students could not make the connection. Staff might have seen the link, but this was not communicated to students. The projects I instigated put more emphasis on employability within the curriculum to make it clear to students what they were doing and why it was important (4.4).

3.2.3 The Mathematics Community

There is no single group or organisation that seeks to promote mathematics as a discipline or speak for mathematicians in industry and/or education. This has long been felt to be a problem for the UK mathematics community in that there is no one body to which government can turn for advice: whereas physics, for example, is represented solely by the Institute of Physics (Smith, 2004). There are currently three main umbrella groups that seek to fill this gap by supporting those teaching the subject at all levels, lobbying government, and communicating the importance of maths to the general public. These are the Joint Mathematical Council (JMC), The Advisory Committee on Mathematics Education (ACME), and The Council for the Mathematical Sciences (CMS).

JMC was established in 1962 to "promote the advancement of mathematics and the improvement of the teaching of mathematics" in the UK (Joint Mathematical Council, 2018). It currently comprises twenty-one mathematical education groups, which in itself explains why it is necessary to have a group to represent their joint interests.

ACME was established in 2002 by the Royal Society (RS) and JMC in order to have one single voice to speak for mathematics education from ages 3-19 in the UK (Royal Society, 2019). Committee members represent different areas of maths education from pre-school to university.

CMS was established in 2001 and currently comprises members of the five main mathematical professional bodies and learned societies in the UK: The Institute of Mathematics and its Applications (IMA), The London Mathematical Society (LMS), The Royal Statistical Society (RSS), The

Edinburgh Mathematical Society (EMS) and The Operational Research Society (ORS) – the latter two joined the CMS in 2008. The CMS was set up "to develop, influence and respond to UK policy issues that affect the mathematical sciences in higher education and research" (Council for the Mathematical Sciences, 2018). It advises on matters affecting mathematics in higher education and research in the UK.

There follows a selective list and commentary of some of the other notable groups in the mathematical community that are important to my context statement.

MSOR Network and sigma

In 2003 the Higher Education Academy (HEA) was established as the result of a merger between the Institute for Learning and Teaching in Higher Education and the Learning and Teaching Support Network (Crawford, 2009). Its main purpose was to support those teaching in higher education to enhance the quality and impact of provision. Twenty-four subject centres were set up to enable those working in similar disciplines to share good practice (Crawford, 2009). The subject centre for mathematics was Mathematics, Statistics and Operational Research (MSOR) and its first Director was Professor John Blake (5.3) (Grove, Brown, Croft, Hibberd, Kyle, Levesley and Linton, 2017). Subsequently, in 2015, the HEA reorganised, reducing the subject centres to four, with maths coming under Science, Technology, Engineering and Mathematics (STEM).

Many of the original subject centres previously published their own journals. The Mathematics subject centre, the MSOR Network, published *MSOR Connections* (3.2.4). This was well used by the community to report findings on key issues and disseminate successful teaching and learning enhancements and projects. In 2013, for funding reasons, the HEA ceased publication of these individual subject-specific journals and many of them were subsumed into one, cross-discipline, journal (Wilson, 2015a). However, a few, including *MSOR Connections*, decided to continue publishing independently. *MSOR Connections* has continued producing three issues per year under a team of four editors of which I was one from 2014-2017. Copies of the two editions I edited are in the Appendix (E1; E2).

The Centres for Excellence in Teaching and Learning (CETLs) programme was instigated by HEFCE in 2005 to "enhance the status of learning and teaching in higher education" (HEFCE, 2018). This provided funding for the start of **sigma** which was originally a CETL focussed on mathematics and statistics support and hosted by Loughborough and Coventry Universities. This work expanded, thanks to further government funding resulting in many universities being incentivised to introduce mathematics and statistics support for students on a wide variety of degree programmes (Lawson, 2015). A report detailing how **sigma** has contributed to providing maths support to students, and thus helping to address the Mathematics Problem, was published in the IMA's *Mathematics Today* in 2014 (Croft, Lawson, Hawkes, Grove, Bowers and Petrie, 2014). I became a member of the **sigma** steering group**,** organising and coordinating meetings and workshops in London and the South East from 2014-2017 and then as the IMA representative until January 2018.

The combination of the CETL and the MSOR Network established the CETL-MSOR conference in 2006. This, now annual, conference series has played a significant role in bringing together HE mathematics lecturers from all over the UK and disseminating good practice and new initiatives (Lawson, 2015). I co-organised the CETL-MSOR Conference at Greenwich in 2015 and have presented regularly at this event. I delivered an invited keynote address on graduate outcomes at the 2018 conference in Glasgow. The HEA runs its own STEM conferences which I have also presented at. However, these tend to be underrepresented by those from mathematics as the conference has such a broad remit and the mathematics community tend to prefer attending CETL-MSOR instead.

Professional Bodies

During the final year of my degree and early part of my PhD I took up membership of the following professional bodies:

I. The Institute of Mathematics and its Applications (2018)
This society comprises both academics and mathematicians working in industry. It is run by a small staff headed by an Executive Director. They are advised by a Council of about 20 members and an Executive Board made up of officers from Council. There are various grades of membership of the society including student membership. Society members can apply to become Chartered Mathematicians, Chartered Teachers and/or Chartered Scientists if they meet certain criteria. The IMA runs various conferences and meetings, offers small grants and publishes several journals. The IMA also runs the Maths Careers website (2018), initiated by the More Maths Grads project (discussed later in this section), which offers an exceptional resource for schools and universities. Many of the innovations I have instigated have been run in conjunction with the IMA of which I am currently Vice President Communications (2016-2019).

II. The London Mathematical Society (2018)
The LMS is mainly comprised of pure mathematicians and has not, in the past, actively recruited undergraduate student members. They run numerous lectures and meetings and administer grants for individuals to attend or convene conferences. They also publish various journals.

III. The Operational Research Society (ORS) (2018)
Like that of the IMA, the ORS membership is comprised of industrial and academic mathematicians. It also has a very proactive schools outreach programme which seeks to educate school children about Operational Research as a career. I was part of the ORS Schools Task Force from 2012-2016 and am still actively involved in promoting OR. The ORS also hosts a large annual careers fair in Birmingham which I took a coach load of students from the University of Greenwich to on two occasions as part of the employability initiatives I instigated (4.4).

IV. The British Society for the History of Mathematics (BSHM) (2018)
My interest in the history of mathematics developed from attending various talks by expert mathematical historians like Robin Wilson. I was a member of BSHM Council for seven years, firstly as Membership Secretary and then as Honorary Treasurer. I am now actively involved in researching the history of mathematics through my talks and recent publication on Florence Nightingale and the origins of data visualisation (Bradshaw, 2017b; E3).

Research conferences

Most mathematicians in HE are expected by their institutions to be research active (3.2.4). Apart from the research I undertook in Computational Algorithms for my MPhil I have been primarily involved in research on Mathematics Education and History of Mathematics. Most mathematical disciplines have their own specialised conferences. In addition, there are two general conferences: the British Mathematical Colloquium (BMC) and the British Applied Mathematical Colloquium (BAMC) which run annually with various streams designed to appeal to researchers in different areas of mathematics. I presented at BMC, York in 2008 and organised the History of Mathematics strand at BAMC, Edinburgh in 2010.

More Maths Grads (2006-2010)

More Maths Grads was a project funded by HEFCE from 2006-2010 to seek ways of increasing the numbers of students studying mathematics undergraduate degrees in England, following the Curriculum 2000 debacle (Easson and McOwan, 2015; STEM Learning, 2009). My contact with the project, towards the end of my degree, fuelled my desire to see more students take mathematics at A-level and subsequently at degree level. Much of my work with the University and IMA has focussed on educating more young people and their teachers so that they are aware of the considerable benefit incurred by pupils who are able to study mathematics at higher levels. One of the outputs of the *More Maths Grads* project was the publication by Robinson et al. (2010a) which looks at the breadth of provision of mathematics in UK universities. A similar workstream called *The*

Mathematical Sciences 2025 (National Research Council, 2013) has taken place in the USA. This discusses the issues affecting the take-up and furthering of mathematics and mathematics research in the US. Many of the themes reported here echo those tackled in the UK by *More Maths Grads, The Mathematics Problem* (London Mathematical Society, 1995) and later in the Bond review (Bond, 2018).

MEI and FMSP

The Further Mathematics Support Programme (FMSP) (previously the Further Mathematics Support Network) was a government funded initiative, set up in 2009 and managed by Mathematics in Education and Industry (MEI). It was initially established to help schools deliver A-level Further Mathematics, where the individual schools did not have sufficient resources, and thus increase the number of pupils taking this qualification which is desired by many universities for entry on to mathematics degrees. FMSP has recently been superseded by the Advanced Mathematics Support Programme (AMSP) (AMSP, 2019). According to Searle's evaluation report (Searle and Barmby, 2012), the increased number of pupils taking further mathematics A-level has also raised the number of pupils taking ordinary mathematics A-level and boosted their achievement in subsequent years. I have worked closely with the FMSP Area Coordinator at Greenwich and elsewhere in London and the South East, putting on events designed to enhance teachers' skills and increase pupils' enjoyment and attainment of mathematics.

National HE STEM Programme

The National HE STEM programme was directed by Michael Grove and funded by HEFCE and HEFCW for three years (2009-2012) in order to explore "new approaches to recruiting students and delivering programmes of study within the Science, Technology, Engineering and Mathematics (STEM)" (Fenton, 2011). Many universities and other interested parties bid for funding, resulting in several new initiatives being established including the Maths Arcade. In mathematics, part of the funding was distributed by the Mathematical Sciences Curriculum Innovation Project, following a Mathematics HE Summit in 2011 (Rowlett, 2011). The summit "presented findings from the curriculum strand of the More Maths Grads pilot project, and was used to develop priorities for curriculum development" (Grove, 2013). Several of the innovations that constitute my public works, were initially funded by the National HE STEM Programme and the Mathematical Sciences Curriculum Innovation Project. A summary of all the projects that were funded in mathematics by the curriculum innovation project can be found in Rowlett (2012b).

3.2.4 Pedagogic Research in HE Mathematics

University academics now have many calls on their time; teaching, administration, management, outreach, marketing as well as a pressing need to be research active and writing quality papers (Fry, Ketteridge, Marshall, 2009). The competent academic is supposed to be able to undertake all these activities despite, for example, teaching requiring different skills to that of a research mathematician (Mason, 2002). As a result of these conflicting pressures many academics are deterred from research into the teaching and learning of their subject (O'Donoghue and Fitzmaurice, 2015). And yet, as O'Donoghue and Fitzmaurice go on to point out, we are letting our students down if we do not conduct research into the best ways to teach our subject.

The British Educational Research Association (BERA) identifies several types of discipline-based pedagogic research (also termed Scholarship of Teaching and Learning (SoTL) (Gurung and Schwartz, 2009), these include but are not restricted to "action research, practitioner research, design-based research, randomised controlled trials and lesson study" (Wyse, Brown, Oliver and Poblete, 2018).

Much of my educational research has been action or practitioner research. These terms are often used interchangeably in the literature and refer to research undertaken in one's own discipline and around one's own practice (Cleaver, Lintern and McLinden, 2018). However, Taber (2016) describes action research as a subset of practitioner research, where action research must be context-driven, iterative and have undertaken several cycles of activity and evaluation in order to improve practice. He quotes Whitehead (1989) as saying that action research is responding to a perceived issue or problem in the researcher's own practice. Most of my public works, such as the Maths Arcade, videos and screencasts, and employability initiatives, went through many iterations and evaluations to improve them and came out of problems that I had come up against in the context of my teaching and interactions with students.

Whilst many Heads of Mathematics Departments and senior HE mathematics educators are aware of these different forms of research into teaching and learning, in general I do not think this is articulated clearly enough to more junior, often overworked, staff who, whilst keen to undertake these activities, can lack the knowledge and understanding around planning and designing research projects in this area or know where best to publish.

When I first started out as a lecturer I thought my research should be all about my PhD studies or theoretical research to do with my lecturing content, so my lectures included new, industry-relevant material. Indeed, I frequently emphasised this to prospective students and their parents at open days and taster events. When I initially had ideas as to how to improve my teaching style / pastoral support of students I did not realise how they could also be turned into a research project. As I discovered first-hand, and others report, there is often little institutional support and encouragement for this sort of research and staff with an interest in this are often left to improve their practice through their own efforts (O'Donoghue and Fitzmaurice, 2015).

However, early on in my career, I was very fortunate that I was encouraged to apply for and be awarded several grants through the National HE STEM Programme. These gave me the opportunity to put my ideas into practise stipulating that the work should be published through specific articles, papers and case studies and/or presented at particular conferences. Another key avenue for sharing innovative ideas was the Ideas Exchange meeting organised by Rowlett that ran for several years (Mann, 2011). This was an excellent forum for discussing ideas, before implementation, enabling the instigators to have early feedback to help shape and hone their thoughts. In particular the Maths Arcade was discussed at the first Ideas Exchange and benefitted greatly from discussion with staff from other institutions such as Keele, Reading and Sheffield Hallam.

At the heart of research in teaching and learning in the mathematics community is MSOR Connections (3.2.3); a peer reviewed journal that publishes a variety of papers including opinion pieces, student articles and book/technology reviews (MSOR Connections, 2018). When the HEA reduced their journals and amalgamated many of them, MSOR Connections decided to become an independent journal and I was asked to be one of the first editors under this new regime which I did for the first two years until leaving academia in 2018 (3.2.3). The editions I edited are in the appendices (E1; E2). The journal continues to publish a wide variety of articles encouraging the mathematics community to innovate and improve HE teaching and learning.

Staff can also feel hampered by university ethics procedures designed for subjects where the human participant receives no direct benefit from the research (Hack, 2015). In some institutions current procedures can seem too stringent given the arguably low-risk nature of the research (Gormon, 2007; Gunsalus, 20004) whereas in others, staff do not seem to realise the need for their research to comply with institutional policy (Hack, 2015; Regan, Baldwin and Peters, 2012; Doyle, Mullins and Cunningham, 2010). As Hack (2015, p.109) says "ethical approval should not be a hurdle, but an opportunity to reflect on research design and receive pre-study peer review; embracing a more constructive approach may go some way to instil confidence and compliance with the process".

Even with institutional support and encouragement it is often hard for busy lecturers to find time to design a research project around their work (Gurung and Schwartz, 2009). This means that some papers can be more opinion-based, describing an enhancement or innovation to current practice, rather than research backed up with quantitative evidence. Taber (2016) discusses the difference between scholarly teaching and learning research papers and papers that just present a 'good idea'.

He categorises good research papers as including systematic evaluation and experiment design and well-researched survey papers.

If I was to go back into HE I would aim to inspire staff across all disciplines to conduct and publish educational research. I would encourage institutions to have a university-wide ethics policy specifically for institutional educational research and look to start staff discussion groups to give support and a way of critiquing ideas. This would also provide helpful advice for setting up educational research projects thus saving time for busy academics.

3.3 Institution and peers

The University of Greenwich has evolved from its origins as Woolwich Polytechnic in 1890. In 1970 it became Thames Polytechnic and then in 1992, along with other polytechnics (3.1) it gained University status, becoming the University of Greenwich (Bradshaw and Mann, 2019). At the time of writing (2018) it occupies three campuses and is organised into four Faculties. The Faculty of Engineering and Science is based at Medway in Chatham, the Faculty of Education and Health is at Avery Hill in Eltham, south-east London and the Faculties of Business and of Architecture, Computing and Humanities (ACH) are based at the Maritime Greenwich campus which is situated at the Old Royal Naval College. When I enrolled as a student in 2004 the University was organised into Schools and the Department of Mathematical Sciences was in the School of Computing and Mathematical Sciences. These Schools were subsumed into four Faculties in 2012.

In 2016-17 the Department of Mathematical Sciences had 280 undergraduate students. These are all taught on campus. In recent years the Department has consistently performed well in the NSS, indicating that students are very satisfied with the teaching and general provision (Bradshaw and Mann, 2019). According to University data gathered in 2018 11% of the 2016-17 cohort are classified as mature with 48% of students being non-white.

3.3.1 Departmental Concerns

Student engagement

Being a post-1992 university, Greenwich tends to attract a large number of first-generation entrants to HE with many from working-class backgrounds thus lacking good networks of family and friends in graduate-level employment. This is across all disciplines and not specific to mathematics. This has often led to students (and their families) not understanding what is required from HE and how to get the most from it (2.1, 2.5, 3.2.2, 4.4.3). Problems can include students wanting, or being expected by their families, to take family holidays in term time, needing to miss lectures to care for siblings or parents, taking time out to take siblings and parents for medical appointments (as they might be the only member of their family to speak English) or being required to work in the family business during their studies. Other problems are often stress-related and may be linked to the issues mentioned above. Many students do not have good time-management skills and so university work builds up alongside pressure from home. It was seeing concerns like this that prompted me to establish the mentoring scheme (2.6.1) in order to free up personal tutor time while providing help to students with these more complex problems. Adaptations of the mentoring scheme were adopted in other University Departments.

Good student engagement is necessary for the high NSS results which Departments want in order to do well in subject league tables (3.1.3). Without this, it is hard to maintain relationships with students and graduates which are fundamental for the creation of a strong alumni network which has the potential to improve graduate career opportunities and advice (3.1.3).

Recruitment, retention and transition

Although mathematics at the University of Greenwich has, over many years, achieved the highest NSS score for satisfaction with teaching in mathematics for a London University, there is still pressure on recruitment of suitable students. The competition for students is immense, with all institutions keen to recruit as many students as they can accommodate, and Greenwich, like other universities, has several strong local competitors. Because of this pressure on numbers there is a complementary pressure on retention (3.1.1). Activities such as the Maths Arcade (4.2) were instigated to improve retention and to aid transition (3.2.2) from both school to university and first year to second year.

League tables

League table position is a constant concern and thus the results from the NSS and DLHE surveys are of paramount importance to the Department (3.1.3). In my time at Greenwich there have been improvements in these which may be linked to some of the employability initiatives that have been put in place (2.6.2 and 4.4.3). There is always a significant number of students who do not want to go into graduate employment. This may be because they want to work in their family business, or because their families do not expect them to work after they are married. Some students travel after their degree and so delay applying for graduate-level jobs or further study. Much of what we have endeavoured to do at Greenwich is to make students aware of the opportunities that are available to them and encourage them to apply for suitable positions.

3.3.2 Initial work in the Department

When I started as an hourly-paid lecturer and PhD student at the University of Greenwich I did not realise that the previous few years had been difficult for the Department of Mathematical Sciences (despite my having just graduated) and numbers had dropped significantly, resulting in the

Department being at risk of possible closure (3.2.2). In order to reverse this trend, the Head of Department had invested time into arranging various taster events for school students to raise the profile of mathematics within Greenwich. He had also encouraged the initiatives I had started as a student, such as the Maths Society and help sessions (2.5). He was keen that the retention of first year students should increase and that anything that either improved the student experience, eased transition from school to University or first year to second year, or promoted the studying of mathematics should be encouraged (2.6.1).

As a recent graduate I had several ideas as to how the student experience could be improved. My enthusiasm and desire to engage with new and prospective students led me to take over the content, and ultimately the organisation, of the summer maths taster events for the whole School. I also initiated several activities designed to enhance the student experience and worked closely with professional bodies, such as the IMA and ORS, to promote mathematics as a discipline worth studying.

It became obvious that engaging and communicating with students was important for understanding how the student experience could be improved. Social Media was new and Facebook in particular was something that several University and Department staff were experimenting with. One of the early initiatives I began was a Facebook group for maths students to:

a) Advertise Department and University events;
b) Encourage students to get help on any area of maths they were struggling with;
c) Foster and promote a greater sense of community within the Department.

This group was so successful that the Director of the University's Educational Development Unit (EDU) asked myself and a group of my students to give input to a staff meeting about using Facebook to aid student engagement. This led to myself, and one of my students, meeting with the then University Registrar and other senior University staff to help draft a Social Media policy. This work is documented in a case study on the use of Social Media in the teaching of HE mathematics by Rowlett (2012a). On the back of this work I was nominated by the University for the THE Innovative Lecturer of the Year award.

Gradually, as a result of an increasing number of innovations, more successful taster events and increasing students' satisfaction, the numbers of applications to the Department rose. This can be seen from Table 1. This successful growth in the Department's intake, as well as increased retention figures and student satisfaction, when other areas of the institution were struggling to recruit, led to myself and the Head of Department being invited to be part of various cross-university task and finish groups on recruitment and admissions under the oversight of the Vice-Chancellor.

Table 1 A table showing increase in applications and registered students in Department of Mathematical Sciences at University of Greenwich

	07/08	08/09	09/10	10/11	11/12	12/13	13/14
Undergraduate applications	294	271	388	442	654	590	613
Undergraduate registrations in year 1	43	76	91	162	121	121	142

3.3.3 Educational Development Unit

My early involvement with EDU put me on their radar as someone who had potential to enhance and innovate the curriculum. I presented my work at many of the annual University Teaching and Learning conferences and published articles in Compass; the University's Teaching and Learning journal. This had the added benefit raising the Department's profile and reputation within the University. My work in this area also resulted in the University nominating me on two occasions for an HEA National Teaching Fellowship.

3.3.4 Career progression

My background (Chapter 2) meant that when I started working as a lecturer I was still quite naïve about the world of work and career progression (2.6). However, I realised that applying for promotions was valuable and that the initiatives I instigated were giving me skills and experiences that showed my capability and leadership qualities. After two years as an hourly-paid lecturer I progressed to an appointment as a Senior Lecturer. In this position, I established a mentoring scheme for new students, initiated the Maths Arcade, and introduced other activities to aid transition and retention (2.6, 3.3.2, Chapter 4). I also worked closely with the University's Admissions and Recruitment Department and saw applications for mathematics undergraduate degrees increase (3.3.2). These initiatives helped me to progress rapidly to Principal Lecturer with responsibility for Admissions, Recruitment and Induction for the whole of the School of Computing and Mathematical Sciences, which included Computing, Film and Digital Media programmes as well as Mathematics. My work here saw numbers for the whole School increase, while they were falling in other parts of the University, and also helped to streamline the School's induction procedure with the result that retention was improved.

In the Department of Mathematical Sciences, I became aware that we could do more to give students guidance on careers (2.6.2 and 4.4.3). I put much time and effort into embedding this into the curriculum for mathematics students and arranging various talks and activities designed to educate staff as well as students, detailed in Chapter 4. When I started, the Department of Mathematical Sciences was one of three Departments in the School of Computing and Mathematical Sciences. The advent of a new Vice-Chancellor in 2011 brought about significant restructuring which amalgamated the Schools into four Faculties. The Department of Mathematical Sciences became one of eight Departments in the Faculty of Architecture, Computing and Humanities (3.3).

Previously each School had been headed by a Dean. Now new Pro-Vice Chancellor (PVC) positions were established to run each of the new Faculties: three of these were filled by previous Deans. The Deans who did not get promoted to PVC level were given new titles of Deputy PVC. A new PVC, Professor Judith Burnett, was appointed to lead the largest Faculty, ACH. On her appointment, she put in place a team of Heads of Department and Directors to form a Senior Management team with her and the newly appointed Faculty Operating Officer. Most of these senior positions were taken up by existing Heads of Department and School Directors: however, I was promoted to the new position of Faculty Director of Employability, presumably as a result of the successful interventions I had made to improve employability for students in the Mathematics Department.

3.4 Collaborations and key relationships

When I began working in academia I did not realise how important it was to have a network of other academics and industry professionals to bounce ideas off, collaborate with on projects, write papers and give joint presentations. My network began growing by chance and, because I naturally see the value of sharing good practice and learning from others, I did what I could to encourage this. Below is a synopsis of some of the groups of people who I have worked with when instigating and rolling out the initiatives described in my public works.

3.4.1 Sheffield Hallam University

I first met mathematics staff from Sheffield Hallam University (SHU) soon after starting at Greenwich when my then Head of Department organised a workshop led by Neil Challis, the then Head of the Mathematics Department at SHU, to encourage new thinking among staff at Greenwich on various key issues surrounding assessment and feedback. I remember being deeply engaged by this; not only were staff from another university experiencing the same problems that we were but they were also thinking up new ways to address them. This encouraged me that I could also find innovative solutions to the problems we were facing; this event was significant in empowering me to initiate both a peer mentoring scheme and the Maths Arcade despite a different topic being the main focus of the day.

Since that initial meeting I have met and worked with many staff from Sheffield Hallam and feel as at home there as I do in Greenwich. Sheffield Hallam was one of the first universities to adopt a Maths Arcade (4.2) with involvement from Jeff Waldock, Claire Cornock, Peter Rowlett and others.

3.4.2 Other universities

I am currently (September 2017) an External Examiner at three other universities. I find this work extremely rewarding as it gives me an insight into the curriculum at other institutions and an opportunity to see how other university regulations and quality assurance processes impact the teaching and learning and thus the student experience. I have had the opportunity to discuss the work we do at Greenwich and have seen some ideas taken on board by staff elsewhere.

Attending workshops organised as part of the National HE STEM Programme and CETL-MSOR conferences has also helped me meet staff elsewhere and provided invitations to visit and speak at other institutions about my work. Such invites are never just one way. I have used these opportunities to find out what other staff are doing and investigate possibilities of further collaboration. For example, one conference presentation led to an invitation to visit the University of West of England (UWE) to talk about the Maths Arcade. Subsequently I have talked to staff there about the flipped teaching that they do and used some of these experiences to guide the work that I have since undertaken in this area.

3.4.3 Staff at Greenwich

It is not possible to set up activities and initiatives without getting support and buy-in from fellow staff. The environment that I worked in when I first started at Greenwich was one that encouraged staff to come up with fresh ideas and to try them out. The wider University was not always helpful at times, so the support of my Head of Department and Head of School was crucial in the early stages of my career.

3.4.4 Industry professionals

My work on employability has led me to form relationships with many professionals working in industry. This has often been as a result of a company hosting a student placement. I have always sought advice from industry as to the skills our students need and how we should be embedding them into the curriculum. I have maintained contact with graduates and invited them back to speak to students. This networking has led to me working with industry professionals in order to write and deliver a new module for final year mathematics students designed to help them obtain a career working with data (Bradshaw and Nicholas, 2017). It also gave me the unlooked-for opportunity to obtain a role as a data scientist and operational research specialist for Sainsbury's Argos which I started in January 2018.

3.5 Summary

This chapter has provided an overview of the Higher Education landscape that I found myself entering in 2007. It has highlighted that, as a result of government policies such as widening participation, there are now far more universities and degree programmes than before (3.1). There is a pressure on universities not only to recruit and retain students (3.1.1) but also to ensure that they have a good student experience. All these factors influence the various league tables and performance measures such as the TEF (3.1.3). This chapter also includes some background theories relating to learning and how this affects the teaching and learning of mathematics both in general and in relation to my works. Discipline based pedagogical research is discussed before moving on to look at the mathematics discipline in more detail. Specific issues such as Curriculum 2000 and the "Mathematics Problem" (3.2.2) are discussed. Mathematical Sciences at the University of Greenwich has not been exempt from these issues. My reflections and autoethnographic approach have shown that the wide variety of innovations that the Department has established over recent years have stemmed from a desire to improve the student experience and thus to increase retention, transition and attainment. These innovations have been disseminated to the wider mathematical community via various conference presentations at BMC, HEA STEM and CETL-MSOR (3.2.3). In some cases these have been published in the CETL-MSOR or HEA STEM conference proceedings or as stand-alone papers in *MSOR Connections* or publications from the National HE STEM programme. Through my network, the Department has made good use of professional bodies such as the IMA and ORS, by hosting IMA evening meetings and daytime lectures and taking students to attend the ORS careers fair. The work that I began in the Department on Admissions and Employability (3.3.4) was recognised by senior managers in the University and has helped shape University policy. This background provides the context for my public works which are described in detail in Chapter 4 and evidenced by material in the appendices.

4 My Public Works

"*Mathematics has always had two surface aspects, often called skills and problem solving… A problem solver needs a rich, connected understanding of mathematics and the ability to see patterns of similarity and association, as well as the skills to carry out the planned attack and to check that the results make sense in the context of the problem.*" Burkhardt and Bell (2007, p.395).

This chapter builds on the themes articulated in Chapter 2, developed using autoethnography and critical reflection, to firstly explain how my childhood experiences and studying as a mature student have contributed to the creation of my public works and secondly discuss how these have impacted the lives of students at the University of Greenwich and beyond. Each public work is introduced by a quote from my reflective journal which gives some background information about how the initial idea was developed. After this, the research methodologies used are not specifically articulated but should be self-evident; they have not been further emphasised to avoid detracting from the readability for the mathematician not so used to these approaches.

4.1 Introduction

My public works have stemmed primarily from a desire to see students' experiences of HE improved particularly in relation to their transitions; first from school to university, progressing from one year to the next and then from university to the workplace (2.6.1 and 2.6.2). In general, my works have helped to create more articulate and confident learners who are better able to contribute their problem-solving skills to today's job market and to inspire the next generation of mathematicians (Bradshaw, 2017a; A1). Many of my graduates have become STEM ambassadors visiting schools and colleges to promote mathematics and other STEM subjects at all levels. Others have gone into teaching, where their enthusiasm for the subject will hopefully encourage others to excel mathematically.

Initially, in the early part of my career, this desire to improve my students' experience led me to instigate various innovations within the Department of Mathematical Sciences at the University of Greenwich focussed on increasing retention, a by-product of improving student transitions and based on my own experiences as an undergraduate (2.6). Critically reflecting on this I have realised that various activities and practices enabled me gain skills more quickly and thus cope well with the numerous transitions I had to make. These include, but are not restricted to, attending outside lectures and conferences, playing strategy board games and puzzles, reading popular mathematics books, giving presentations, joining mathematical societies (at the University and outside), participating in group work, and using critical self-reflection to improve performance. The following sections of this chapter describe each public work in turn, followed by evidence of its significance and impact. Each section concludes with a critique of the work with further evidence supplied in the appendices).

4.2 Maths Arcade

> "January 26, 2010.
>
> Today we went to a meeting run by EDU on transition. Apparently, there is University funding available for projects to help students transition between first and second year and school to University. I came up with the idea of a drop-in session where our students can play strategy games and puzzles in an informal relaxed atmosphere, ideally with a vending machine so they can get food and drink, and a place where staff are also present, so the students can ask about tutorial sheets that they are stuck on."

The first Maths Arcade (initially called the *Mayhematics Café* [sic]) started in 2010 as a weekly drop-in session where mathematics students could engage in strategy games and puzzles with lecturing staff, PhD students and their peers and also obtain help with any of the mathematics that they were studying. As described in the diary excerpt above, my motivation for this venture was a response to an internal funding call to provide a vehicle to enhance transition for new students from school to university and to help first year students transition into the second year (Bradshaw, 2017a; A1). At the time, I had recently implemented a peer mentoring scheme (Bradshaw, 2011b) whereby second year students mentored new first year students and increased the range of induction activities to help new students form friendships faster and settle in more quickly (2.6.1). The University was keen to offer a small amount of seed funding to projects designed to further aid transition either to or from the first year and, after discussion with other Department staff, this project took shape.

As is often the case at post-1992 institutions, our student intake came from academically diverse backgrounds (Toman, Leahy and Caldwell, 2005) (3.3.1). At one end of the spectrum we had well-qualified students with A grades in A-level maths and further maths whilst at the other end we had some students accepted with non-traditional entry qualifications such as Access courses or A-levels taken several years ago; these students tended to be less familiar with the content of the current A-level syllabus. Regardless of the level of qualifications, students from non-traditional backgrounds tend to need more support as they often have family problems or issues with confidence and self-worth (Crozier, Reay, Clayton, Colliander and Grinstead, 2008) (2.4 and 2.5). As I was familiar with the above issues it seemed important to provide an activity or resource that could be accessed by students from all backgrounds and had the ability to both stretch those who needed stretching whist simultaneously providing support and help for those who took longer to assimilate material or found that they had gaps in their previous knowledge (Bradshaw, 2011b).

I was aware of the University of Portsmouth's Mathematics Café (Pevy, 2010) which operated as a drop-in centre, near the Student Union café, staffed by members of the Mathematics Department. It provided help on mathematics for all students at the university in a relaxed and informal venue. We had previously tried to set up mathematics support sessions for maths students at Greenwich, but these had largely failed due to students being reluctant to ask for help, and the support being provided by only one, already overstretched, member of staff (Bradshaw, 2017a; A1). However, I could see that having a time and space where mathematics students could meet with lecturing staff in an informal setting (preferably with food and drink available) would enable them to see lecturers as "being human" (Mason, 2002. p.57) and increase students' confidence to enable them to ask for help.

Being new to academia I still remembered what I had found helpful both as an initially struggling first-year student with low self-confidence to one who quickly gained proficiency and needed stretching. One of my significant motivators at the end of my first year was reading Polya's *How to Solve it* (Polya, 1957) and John Mason's *Thinking Mathematically* (Mason, Burton and Stacey, 1982) (3.2.4). Polya (1957, p.v) writes primarily for the mathematics teacher encouraging them to "challenge the curiosity of [their] students … [to] give them a taste for, and some means of, independent thinking." He goes on to give examples of open questions that the teacher can ask to help put the student on the right path but not give them the answer. He is keen that students learn the joy of problem solving for themselves and suggests four phases of approach: Understanding the problem, devising a plan, carrying out the plan and looking back. Mason (1982) picks up these phases but explains them directly for individual students rather than the teacher. He also emphasis the benefits of being "stuck" describing this as "an honourable and positive state where much can be learned (Mason et al., 1982, p.45)." At this point I realised that success on a mathematics degree was more than just learning the methods taught in lectures. By learning to think mathematically I found myself becoming better at puzzles such as Sudoku and Scrabble. I began playing strategy games like *Quarto* and *Pentago* which in turn then seemed to improve my mathematical ability and logical thinking. The pressures of juggling studying for a degree as a mature student with the needs of a young family meant that I had little opportunity to reflect at the time on why my problem-solving skills were improving or how strategy games helped but I just remember recognising that this appeared to be the case.

Indeed, even as a new lecturer, I still had little space to critically reflect on and research the connection between playing strategy board games and one's increasing prowess in logical and mathematical thinking; it just seemed obvious to me, based on my observations, that these activities, which I had taken up in the vacation after my first year, had contributed to me outperforming my peers in the second and final years of my degree. I had observed that my classmates seemed to need time to catch-up after their summer break, during which they had usually undertaken no cognitive past-times, whereas I needed no such break-in period and was able to hit the ground running. So, with these thoughts in mind, I persuaded the Department of the viability of my idea and decided to plan weekly drop-in sessions, open to all mathematics students, that provided somewhere they could visit to ask questions and obtain support, as well as somewhere where they could play strategy games and work on puzzles in order to develop their mathematical thinking and problem-solving skills. Now, with more experience, I would make sure that I undertook a review of the literature and engaged in consultation with colleagues to help me evaluate the substance of my ideas and put the Arcade on a sounder pedagogical footing from the start. More details, including an evaluation of the first year of running the Arcade are in Bradshaw, Parrott, Lakin, Mann and Sharp (2012) (4.5).

4.2.1 Significance

A year after the start of the *Mayhematics Café* [sic] we changed the name to The Maths Arcade, in consultation with others outside of the University of Greenwich at the fist Ideas Exchange (Mann, 2011) (3.2.4, 4.2.2), as we needed to differentiate it from other Maths Cafés that only offered maths support.

The Maths Arcade was immediately popular with Greenwich students. All staff were expected to attend and use it as the place where students were met and problems dealt with. In the previous year, 2009-10, first year pass rates had been disappointing and had given cause for concern (Bradshaw, George, Lakin, Mann and Ramesh, 2012). We were keen to see this turned around. However, for various reasons, outside of the Department's control, the University had recruited an exceptionally large number of mathematics students for the 2010 intake and so, in the first year the Arcade ran, the first-year group was bigger than expected with a greater than usual number of students with lower entry qualifications. Despite this, at the end of that year, retention rates were pleasingly high and first-year pass rates had increased significantly compared to the previous year (Bradshaw, 2017a; A1). Not only this, but the year group had integrated with each other much more successfully than in previous years and there was a large core group of students that reached out to many other friendship groups. As usual there were some students in the year with significant problems; the father of one of the students had contacted me before term started to say how worried he was about his son making friends due to issues with depression. But this was one of the first students to start attending the Maths Arcade and, through this, he made a large number of friends and had no problem in settling into the year. He is now a successful secondary school teacher and a graduate of the government-funded mathematics teacher training scholarship programme administered by the IMA. He, and many other students from that year group, cited the Maths Arcade as being significant in helping them settle into the University and their academic studies.

The structure of the Maths Arcade meant that students naturally got to know each other as they interacted whilst playing the games. Rather than play competitively, students were encouraged to ask questions about the games; for example, is there an advantage to playing first or second and are there other rules that one could introduce to vary the game play; is there a winning strategy or strategies? Questions like these were designed to aid students' strategic and mathematical thinking but also designed to help them interact with each other.

Another aspect of the Arcade was the interaction between staff and students. Other activities that we had run previously had always included both groups, but this was the first where they attended on the same level. Many students have commented that they enjoyed playing against staff at the strategy games and, in particular, beating them (Rowlett, Webster, Bradshaw and Hind, 2019). As described above, the act of 'competing' with someone at the Arcade is a communicative activity so competing against a lecturer meant that the students and lecturers got to know each other better and a friendly staff/student community began to develop. The importance of staff/student interaction is commented on by Trowler and Trowler (2010): "interacting with staff has been shown to have a powerful impact on learning especially when it takes place outside of the classroom". Further benefits of developing staff student communities are discussed by Croft and Grove (2015).

4.2.2 Impact

As a result of speaking about the Arcade at a QAA workshop in Exeter and then subsequently at an *Ideas Exchange* meeting in Birmingham (Mann, 2011) there was much interest shown by other universities in starting their own Arcades. Initially six others were set up: Bath, Keele, Manchester, Nottingham, Salford and Sheffield Hallam. Since then, other HEIs have started their own, these have included: Essex, Leeds, Leicester, Newcastle, Reading and UWE. Other HEIs and schools have purchased games, but it is not clear if they have set up similar sessions; these include Birmingham and Kingston. Some of the Arcades run on very similar lines to Greenwich; for example, Sheffield Hallam (Cornock, 2015; A3) whereas others such as Bath operate within the Maths and Statistics Help Centre (MASH) and are therefore designed to include students from other STEM subjects.

Many of the above Arcades were set up with money from the National HE STEM Mathematical Sciences Curriculum Innovation Project administered by Rowlett. Articles about these Arcades, highlighting both the differences and the similarities, can be found in Bradshaw and Rowlett (2012; A2). This publication gives a good account of the variety of Arcades that now exist and ideas on a variety of ways of running them. Money for setting these up has also been provided by small educational IMA grants and internal institutional funding.

The Maths Arcade model has also been used to initiate similar activities in other disciplines for example the Accounting and Finance Department at the University of Greenwich run a similar games-based activity to aid students with employability skills. The Business Faculty lecturer responsible for this was nominated in July 2017 for a prestigious institutional award as a result of this activity.

4.2.3 Critique

As previously said, when the Maths Arcade started the student intake spanned a wide breadth of ability. Whilst it was relatively straightforward to identify and help those students requiring extra support (Croft, Duah and Loch, 2013), finding ways to stretch the more able was harder. Having been in this group of students recently myself (my marks for courseworks and exams were usually well in excess of 90%) I recognised the importance of this. I also realised, from self-reflection and dialogue with current students, that although this group of learners were bright, their mathematical thinking and strategic reasoning skills were not always so well developed. As Houston (2009) says, obtaining the right answer does not mean that full understanding and clarity of thought has been displayed. Thus, rather than provide them with extra mathematics questions (indeed non-essential stretching questions on tutorial sheets were rarely completed), I sought to devise a way to develop their thinking skills. This built on work we had done in the first-year module Mathematical Thinking and Technology (Bradshaw et al., 2012) where we used various examples from the works of Polya (1957) and Mason (1982). However, the difference with the Maths Arcade was that we wanted an optional activity that had to be fun (so students attended), enabled students to get to know staff and provided a safe environment for giving support to weaker students (Croft and Grove, 2015).

Devising and playing strategy games to promote mathematical thinking is not new. Many great mathematicians such as John Nash and John Conway have experimented with games and recreational mathematics. Whilst Conway worked at Cambridge he invented numerous pen and paper and board games including the well-known *Game of Life,* which is played with stones on a very large chess board. He is reported by Roberts (2015a) as being the perpetrator of endless gaming sessions in the mathematics common room which ultimately elevated games to a suitable subject for serious research. Interestingly he wasn't motivated by winning but rather enjoyed investigating all the possibilities in the game, which is exactly what we have tried to encourage with the Maths Arcade. Roberts (2015b) writes that Conway sees games before numbers. In other words, he starts by playing a simple game and then extends it to explore where this might take him mathematically. Indeed, his surreal numbers came about after trying to classify the moves of players in a game like Go. This questioning, described by Wells (2012, p.56) as "meta questions, questions about the game that will not make you play better" is encouraged in the Maths Arcade. Rowlett gives an example of this when looking into various strategies of a game called Quarto which is played on a 2D 4x4 board (Rowlett, 2015). In a subsequent paper (Rowlett et al., 2019) the game is extended to other dimensions and finally generalised to an nxn board.

John Nash, was one of the popularisers of the game Hex. Originally discovered in 1942 by Piet Hein, a Danish scientist and mathematician, it was 'rediscovered' by Nash in 1948 whilst at Princeton (Gardner, 1959; Gale, 1979). Hex is typical of the games we encourage students to play at the Arcade as it is incredibly easy to understand the rules, quick to play and yet there are numerous intricacies and subtleties that take time to assimilate, in order to play strategically. The beauty of this type of game is that anyone can sit down to play; you do not need to be mathematical and you can even draw the grid on paper. Once you have played (and lost) a few games you quickly develop ways to block and try and beat your opponent. This sort of strategic thinking is not one that can be developed in many other ways. It is mathematical in that it is working through a problem and trying a variety of different solutions and seeing the game develop several moves ahead. This method of thinking is required by computer programmers, logicians and those working in artificial intelligence as well as mathematicians.

The best-known game for developing this sort of strategic thinking and game-play is Chess. There are organisations committed to encouraging more children to play chess specifically because the game is perceived to help develop clear strategic and mathematical thinking skills. There is also some evidence that it has been beneficial in encouraging disruptive pupils to concentrate for longer. However, we did not want to encourage games like Chess or Go in the Arcade sessions as these games take much longer and work best if opponents have similar levels of ability. With the other games previously mentioned, players' ability and experience are not as much of an issue as the rules are simple to understand so strategy can be acquired quickly by those who have played less often. Because the games are much shorter, typically fifteen minutes at most but usually nearer five, it does not take long for players to master the rudiments of the games.

In 2016, five of the universities running Maths Arcades worked together to evaluate the provision (Rowlett et al., 2019; A4). Just under 300 students from University of Greenwich, Nottingham Trent University, University of Reading, University of Salford and Sheffield Hallam University took part in the research. The remit of this research focussed on the following key areas:

- Attendance (factors felt to contribute to this);
- Session content;
- Social interaction;
- Staff involvement.

Results suggested that students value the games' content and understand the reasons for the activity. Several cited building friendships as being a key factor in their decision to attend and 95% of respondents said that they wanted at least the same number of staff attending, suggesting that this was an important factor.

Another important factor behind the concept of the Maths Arcades is that of aiding transition and thus increasing retention. One of the key features of the Maths Arcade is that it enables different year groups on a degree to mingle in a social setting whilst retaining some element of academic content. There is much in the literature about student collaborations; "working with students who have recently been through the same experience also helps increase their confidence and self-efficacy" (Walker, 2015, p.75). In a case study on the Maths Arcade I describe the beneficial effects as being a higher pass rate for first year students as well as improved communication skills and confidence in tackling unfamiliar problems, as evidenced by the National Student Survey (Bradshaw, 2017a; A1). These NSS questions on communication skills and confidence are ones that traditionally mathematics students answer negatively (Gillard, 2017). However, students from Greenwich have been far more positive about the communication skills and confidence that they have gained since the introduction of the Maths Arcade. This case study (A1) focusses on first year retention and transition from school to HE: new first year students are likely to feel concerned about settling in, be worried about making friends, have anxiety about the work being too difficult or conversely worried that the work might not stretch them enough (3.2.2). The Maths Arcade has been seen to alleviate some of these threats and anxieties and thus aid transition at the start of a student's degree programme.

The Arcade was also initially set up to ease students transitioning from first year to second year. First year retention issues are often tackled by increasing support from personal tutors and mentoring schemes or by recapping a small amount of A-level material. It is therefore no surprise that many university departments, focused on first year retention, often report greater problems in the second year as the extra help and support diminishes (Croft and Grove, 2015). Some students will welcome the more challenging work and environment whereas others will flounder. The Maths Arcade can act as a safe fixed point in the student's week throughout the whole of their degree. It encourages students from different years to talk to each other and access support from lecturers who have taught them previously, as well as other lecturers that might be teaching them in subsequent years. This continuity, and opportunity to get to know more students and staff than is usual in the first year, is very beneficial. However, more research is needed in order to investigate if this activity improves transition for new second year mathematics students.

4.3 Tomorrow's Mathematicians Today

> "November 16, 2008.
>
> I had an amazing idea whilst in the bath this morning. I was thinking back over yesterday's trip to the IMA conference and wondering what it would take to get undergrads engaged in this sort of event. Then it dawned on me - they need their own conference! Somewhere they could present their own research (like I did on Galois in my final year) to other undergraduates. I can really see this working but need to persuade Tony and Peter first."

As discussed in section 3.2.1 the undergraduate mathematics curriculum varies from university to university (Robinson et al., 2010a). As an undergraduate I attended many talks and conferences run by organisations like Gresham College, BSHM and the IMA. Amongst the talks that I still remember today, and which therefore made a particular impact on me at the time, were the history of mathematics lecture series at Gresham College by Professor Robin Wilson, a lecture on Tropical Mathematics at BMC in York and a keynote on the teaching of mathematics and science at the Research in Progress meeting run by BSHM in 2007. These events opened my eyes to other areas of pure and applied mathematics that were not covered by the curriculum at Greenwich. I realised, that being aware of other mathematical areas that existed, even if I hadn't studied them in depth, increased my understanding of mathematics as a whole and thus enabled me to better appreciate connections between different mathematical topics. Consequently, I wanted to make sure that my students had similar opportunities to myself. In my first year as a lecturer, as well as advertising local events at Gresham College, I also arranged to take a group of second year students to the IMA's Early Career Mathematicians conference. This was a good experience and the students appreciated it, but I was concerned that some of the material presented was far too advanced for them, as many of the talks that year were from PhD students speaking about their area of pure mathematical research rather than the more accessible maths used in industry.

This started me thinking about what we could provide for students to help increase their awareness of different mathematical topics whilst keeping it at an accessible level. As described in the diary excerpt above, I came up with the idea of arranging a conference just for mathematics undergraduates, with undergraduate speakers and delegates, run as any other mathematical conference with a mix of parallel streams and plenary sessions. I thought that having a well-known keynote speaker would help to attract a good-sized audience.

I discussed the idea with Peter Rowlett who was the then IMA Undergraduate Liaison Officer (ULO) and Tony Mann, then the Head of Department at Greenwich. Both were initially a little sceptical but did not say no outright. Their main concern was whether enough students would attend, either as delegates or presenters. As a result of a joint proposal from Rowlett and myself, the IMA agreed to provide some funding as long as we also asked participating universities to contribute. This was rather complicated to arrange but it enabled the first conference to go ahead.

After discussions with Rowlett and Mann we decided to call the conference Tomorrow's Mathematicians Today (TMT). Greenwich Maths Society students helped to plan and organise it and one of our students designed the logo. At this first conference, universities were asked to pay £10 for each of their students who wanted to present a paper. To our surprise this did not deter universities and we had over 30 undergraduates from 11 different universities submit an abstract, almost all of which were accepted. Professor Ian Stewart, the well-known mathematician and author of many popular maths books, gave the keynote talk *Mathematical Curiosities and Treasures from Professor Stewart's Cabinet* and 130 undergraduates registered to attend from 22 different institutions. Funders and participants declared the event a great success, with many asking when the next one would take place. It was reviewed in the IMA publication: *Mathematics Today* (Bradshaw, 2010). The conference has since been the subject of a presentation at a University of Greenwich Teaching and Learning Conference and disseminated in the conference proceedings (Bradshaw, 2012e; B2).

4.3.1 Significance

Tomorrow's Mathematicians Today was the first ever undergraduate conference in mathematics in the UK. Its origins are detailed on the current conference website administered by staff from the University of Greenwich (TMT, 2018; B1). My research at the time showed that similar formats had been adopted successfully in many US state universities, such as New Jersey, California and Illinois, but no one had ever tried to organise one in the UK for mathematics (Bradshaw, 2012e; B2). Many of these are supported by the Mathematical Association of America (MAA) (MAA, 2019) but there are many others run by individual universities or groups of universities (Hilderbrand, 2019). The high specialisation within the discipline is one of the reasons why it is more necessary in mathematics than in other subjects. Once one starts a PhD in mathematics the content of any papers written and delivered, soon becomes unintelligible to anyone working outside the same area, even if they have a mathematical background (Stewart, I., 2006; Cheng, E., 2015). I have heard quite eminent, well-known group theorists declare that they know nothing about some quite elementary mathematical physics because it is not their area. Conversely, someone who has studied applied mathematics might have a very limited understanding of rudimentary number theory. This is one of the features that sets science, and especially mathematics, apart from other disciplines where, even if the details are not all grasped, an undergraduate can usually follow the key aspects of a research paper on English Literature or History (Stewart, 2006; Frenkel, 2013).

The undergraduate mathematics conferences in America vary greatly, ranging from one to five days in length as can be seen from the list supplied by Hilderbrand (2019). They all seem to be aimed at giving undergraduates an opportunity to present some interesting research to an audience comprising undergraduates from universities within the same state or geographical region (MAA, 2019). Many have keynote speakers and some of them charge fees whilst others are funded by the private sector or grants (MAA, 2019). When organising the first TMT it was thought that it might become geographically-based; as a conference in Greenwich might attract only those students south of Birmingham whereas a conference in York might not attract those from London, Kent and the South West. However, very early in the advertising of the first TMT at Greenwich we had enquiries from the Mathematics Department at St Andrews, Scotland asking if it was possible to attend, which showed that distance did not appear to be an obstacle (Bradshaw, 2012e; B2). The St Andrews delegation obviously thought the experience was worthwhile but the distance a deterrent as they have since had their own in-house version (Desai, S., 2017). Ideally, I didn't want to ask universities to pay for their students to attend but as this was a condition of obtaining IMA funding it was necessary for the first event. Subsequent conferences have been free for university students (members of the public are charged a nominal sum to cover refreshments). Other costs are covered by an IMA grant and funding from industry (Bradshaw, 2012e; B2).

When planning the first conference I realised that there were many benefits for the undergraduates who were speaking as well as for those attending (Bradshaw, 2012e; B2). Speakers obtain the experience of presenting to a non-specialist (though reasonably technical) audience. They have to learn to present within a specified time slot and, of course, have prepared something interesting to talk about; skills much sought after in industry (Sodhi and Son, 2007). The conference is not aimed at those on MSc programmes: thus the idea is for undergraduates to undertake some research, not necessarily original, of their own alongside their degree. This, in itself, is incredibly beneficial (4.3.3).

One of my students, who spoke at the first conference on the mathematics behind the game show *The Weakest Link,* used the experience to get a place on a good industry graduate programme and is now employed as a writer of quiz show questions for *The Chase*. Similarly, other speakers have found that future employers have been very interested in their experience at TMT.

For those students attending without presenting, it provides an opportunity to hear about and be inspired by areas of mathematics that they might not be familiar with. This might enable them to see new connections with different areas of mathematics, and might offer ideas for future research projects either at undergraduate or postgraduate level or other potential careers. All student delegates learn how professional and research conferences work in general. So, regardless as to whether they were planning to go straight into a career after graduating or to stay at University for further study or research, the conference holds some value and the experience is very beneficial (Bradshaw, 2012e; B2).

4.3.2 Impact

The initial conference was incredibly successful. Over 30 students from 11 universities spoke, with a total of 130 attendees from 22 universities. There was a wide variety of universities involved including Cambridge, Imperial, Exeter, Brighton and London Metropolitan, with students coming from institutions as far afield as St Andrews and Plymouth. The feedback from attending students and lecturers alike was extremely positive about the whole event including comments such as:

I would like to thank you for giving me a chance to become a part of such an event. It was a fantastic life experience to me. I learned a lot and also met great people who are genuinely interested in Mathematics. Final year undergraduate, Royal Holloway, 2010.

Thanks again for organising the conference - everyone I spoke to got a great deal out of it and are eager for something similar to happen again. Lecturer, Exeter, 2010.

IMA Council were delighted with the success of the conference. We thought it was very well run and that all the students involved - those presenting and those attending - got a lot of benefit from the experience. They were so pleased with the conference that they have decided to continue the series. IMA representative, 2010.

These quotations and others can all be found on the conference website (TMT, 2016; B4).

As the final quote suggests the conference was such a success that the IMA decided that it would be worth them contributing to the running of the event on an annual basis at a volunteer institution. Unfortunately, their first volunteer for 2011 fell through so, after a delay, Greenwich volunteered to run it again in 2013. Since then there has been a TMT conference almost every year in venues such as Surrey, York and Manchester (Ellis, 2017; B3). They have all been run slightly differently but the main ethos remains the same that it is for undergraduate mathematicians to present their work to an undergraduate audience. The seventh TMT is due to take place at Greenwich in February 2019. Other university-based undergraduate mathematics research conferences, such as St Andrews (2019), have subsequently taken place.

Since 2013 GCHQ, the largest employer of pure mathematicians in the UK, have funded a prize for the best paper as they see the conference as being significant for mathematics undergraduates and thus well worth supporting. As an organisation GCHQ understands the need for STEM graduates to have good communication skills as well as significant mathematical ability. They see TMT as helping to encourage these skills.

However, the greatest impact has been on the individual students who have attended and taken part. Some I am still in touch with via social media. The quote below from a speaker at the first conference sums up many of the other comments students have given to me verbally.

"Speaking at TMT was undoubtedly the highlight of my mathematical career thus far. My TMT research when coupled with my third-year studies has enabled me to come up with an excellent dissertation idea. My confidence and skills in public speaking were enhanced incredibly and has been a prime experience to use when applying for graduate jobs. Employers are especially impressed at the amount of motivation and passion required to voluntarily research a topic and present your findings to such a large audience. I was also able to gain excellent feedback from students at other universities, allowing me to look at my research in new ways." Third year undergraduate, Greenwich, 2011.

4.3.3 Critique

As stated in Bradshaw (2012e; B2), research and inquiry-based learning at undergraduate level are important. I was aware of the research by Mick Healey and Alan Jenkins (2009, p.3) who say that "all undergraduate students in higher education institutions should experience learning through, and about, research and inquiry." TMT encourages this. Whilst most maths curricula include a final year research project at undergraduate-level, not all do (Robinson et al., 2010a). Also, some students like to undertake some research on their own during the summer before their final year, or to read about different areas of mathematics throughout their studies. TMT encourages students to be research-active and to have an open and inquisitive mindset to the mathematics around them. Previous TMT presentations have included talks on the mathematics of Sudoku puzzles, mind-reading tricks using Hamming Codes, and the link between mathematics and music, as well as very deep contemporary research mathematics such as Banach Algebras and Quantum Computing.

Although at this point in my career I was not aware of inquiry-based learning (IBL) I knew that learning things for myself by researching a topic from scratch had improved both my research capabilities and my retention of information. I later realised that the theories of inquiry-based learning were at the heart of the conference and have a clear link with the Constructivist theory that had resonated with me prior to becoming a lecturer (3.1.4, 3.2.4). Roy, Borin and Kustra (2003) define IBL as a form of self-directed learning where "students take more responsibility for determining what they need to learn, identifying resources and how best to learn from them, using resources and reporting their learning, and assessing their progress in learning". There are other benefits mentioned in the literature. These include the honing of critical thinking and problem solving (Justice, Rice, Warry, Inglis, Miller and Sammon, 2007; Spronken-Smith and Walker 2010), developing research skills (Goodyear and Ellis 2007; Goodyear and Zenios 2007) and improving written communication skills (Justice et al. 2007). But it is not only the act of research and discovery that is important. The US-based Boyer Commission on Educating Undergraduates in the Research University (1998, p.24) states that "dissemination of results is an essential and integral part of the research process." Indeed, both these themes; that of independent inquiry and presenting results to an audience are said by Boaler (2016) to be crucial for students to develop and enhance their mathematical thinking.

In recent years many universities have introduced more inquiry-based modules into the curriculum. These include *Developing Mathematics Reasoning* using the Moore method at the University of Birmingham; *Problem Solving*, a first-year module inspired by Mason (1982) at Durham University; *Investigations in Mathematics*, a second-year module at the University of Leicester and *Mathematical Problem-Solving* a third-year module at Queen Mary, University of London (Badger, Sangwin, Hawkes, Burn, Mason and Pope, 2012) and the mathematical modelling module at Sheffield Hallam (Rowlett, 2017). Although these, and many others, run on different lines with different emphases and different assessment structures the common theme is that they all aim to give students skills and practice in solving mathematical problems where the process for answering it is unclear (Badger et al., 2012). The value of these and similar modules is primarily down to the perception that employers value mathematicians due to their ability to solve problems and they expect graduates to be able to do this in unfamiliar situations (Badger et al., 2012; Sodhi and Son, 2007; Waldock and Hibberd, 2015; Hawkes, 2015).

Each year the success of TMT depends on how well the hosting institution advertises and organises the event. Guidelines are distributed via the IMA's current ULO and I am available for consultation. We have provided a suggested timeline as to what should be done and when, such as issuing a call for papers and agreeing the programme etc. This variation can lead to differences in the number of speakers that are accepted, the topics which are presented and the number of delegate attending. Apart from these differences the conference is also dependent on lecturers from HEIs promoting it to their students and encouraging students to submit abstracts. The conference is advertised via the IMA's website (IMA, 2018) and publication *Mathematics Today* which broadens its advertising reach.

4.4 Business Game and other employability initiatives

> "December 8, 2009.
>
> Feeling very down today. Spoke to Joe and Hannah after the project presentations today. It is clear that they know nothing about how to apply for jobs and feel they haven't got enough about this from their degree or the University. I want to do more for them but what? I will talk to Elena and see if we can come up with a plan."

As an undergraduate I received no help from the Mathematics Department regarding careers, or at least that was my perception at the time (2.1, 2.6.2 and 4.4.3). I graduated with little understanding as to what you could do with a maths degree apart from teaching, which had been my initial motivation for studying the subject. As described in the diary excerpt above, I was devastated when I realised that my first cohort of students were about to graduate with little idea of future career plans (2.6.2). Having put so much time and energy into aiding their transition and retention when they first started, and now realising that we had not provided the necessary support for them to readily transition into the workplace, made me feel that I had significantly let them down. Consequently, I realised that this was something else that we needed to address either within the mathematics curriculum or through Department-based extra-curricular activities. At around the same time, through serving on the IMA's Web and Image Committee I became aware of the IMA's Maths Careers website, an output of the *More Maths Grads* project (3.2.3), and I started attending talks on careers run by the University's Employability Team (GET) which introduced me to employers who educated me as to what they wanted from our graduates. I also attended several CETL-MSOR conferences and started reading the journal *MSOR Connections*; through these media I came across papers by other HE mathematics lecturers such as Challis, Robinson and Thomlinson (2009) and Hibberd and Grove (2009) who were addressing the employability provision of mathematics students (3.2.2).

As a result of these interactions, and through discussions and collaboration with academics from other institutions, I have initiated a range of employability tools and activities which, when combined, have helped more mathematics graduates at Greenwich obtain graduate-level jobs or further study positions within six months of graduation. Table 2 shows the percentages of mathematics and Faculty-wide graduates obtaining graduate-level positions within six months of graduation. The students graduating in 2012 had not been given much information on maths careers whereas the students graduating later had experienced a much greater amount of input as a result of my initiatives across all their years of study.

Table 2 A table to show the percentage of mathematics and Faculty-wide students obtaining graduate-level outcomes in the DLHE survey

Year of graduation	Mathematics	Faculty
2016-17	71%	67%
2015-16	75%	61%
2014-15	72%	60%
2013-14	53%	57%
2012-13	62%	56%
2011-12	58%	54%

The main initiatives were: a business game (C1), an employer-endorsed personal development planning (PDP) assessment (C2), and an annual event called *Maths Graduates: Where are they now?* where graduates were invited back to Greenwich to talk to current second year students (C3). More recent initiatives have included designing and running a final year module on Data Analytics that was created with significant input from industry (Bradshaw and Nicholas, 2017; C4).

These initiatives have all helped students transition from undergraduate study to graduate employment or further study. Critically reflecting on these projects, using an autoethnographical approach, I can see that what these initiatives have in common is that they are all vehicles that encourage students to reflect on their current position and provide them with tools designed to encourage them to embrace new skills and experiences to make them more employable. These initiatives reflect the adult learning principles described by Knowles et al. (1984) (3.1.4) by encouraging students to self-direct their own learning, to understand how their life experiences (to-date and in the future) can be a source of learning and transferable skills, to motivate them to look towards the future and to take action to learn and achieve. These reflections are echoed in practitioner-based research by Challis et al. (2002) who assert that embedding transferable skills and reflective practices into the undergraduate mathematics curriculum have improved students' adaptability, study and communication skills, and by Yorke and Knight (2006) who list some of the personal benefits of including transferable skills as being a belief that intelligence is not fixed and can be developed, awareness of one's own strengths and weaknesses, increased confidence in dealing with the challenges that employment and life throw up, an ability to work without supervision, resilience, commitment to ongoing learning to meet the needs of employment and life and the disposition to reflect evaluatively on the performance of oneself and others.

The business game is described in Bradshaw (2013a) and Ramesh, Mann and Parrott (2014). It is run like many of the graduate assessment centres used by employers in the graduate recruitment cycle, providing the students with a competitive group activity. It was designed in collaboration with the IMA and consequently has professional-body endorsement. Students who take part are encouraged to take up IMA membership; the benefits of which are explained during the activity. A student's view of the activity can be found in the appendices (Wolfin, 2014; B1).

The employer-endorsed PDP assessment is an assignment that is worth 10% of a 30-credit module. It has been disseminated at various conferences and is described in Bradshaw (2014; C2). It comprises several components including requiring students to complete a CV, mock job application, cover letter and LinkedIn profile. Employers have commended the comprehensiveness of the assignment, describing it as "an excellent model … I especially liked the Standard Application Form which should, if well thought through by the student, prepare them for almost any formal application" (Bradshaw, 2014).

Realising that many of our students are first-generation participants in HE, lacking role models in graduate employment, I felt it was important to provide examples of the achievement of other students from similar backgrounds. Through a call from the HE STEM Mathematics Curriculum Innovation Project to apply for grants to put on events similar to those mentioned in Waldock (2011) I obtained money to run an activity similar to Walker's Calculating Careers event (Walker, 2009). The event I ran, *Maths Graduates: Where are they now?* is detailed in Bradshaw (2012a; C3) and Bradshaw (2012b) and has become an annual occurrence in the Greenwich Mathematics Department.

4.4.1 Significance

These initiatives provided a starting point, enabling myself and other staff in the Department to understand more about the variety of careers available to a mathematics student and, particularly importantly, the skills that graduates need in order to obtain a good graduate-level job. As a result, many Department staff became involved in other projects to help improve graduate outcomes. We obtained funding from the South East spoke of the National HE STEM Programme for a student employability project where we partnered with the charity, the Adab Trust, whose mission was to enhance BAME students' career opportunities and raise their aspirations. The partnership provided a series of CV clinics, workshops and masterclasses designed to help educate students regarding the careers available to them and the skills that they needed to acquire in order to take advantage of these opportunities (2.6.2). The project is discussed in a short video (Bradshaw, 2012d) and report (Bradshaw, 2012c). As well as running sessions for students, the Adab Trust provided a series of events for academic staff. These incorporated some team-based activities to encourage staff to work together and also showed examples of the sort of team-building activities that could be carried out with students to help boost their confidence and problem-solving skills. A similar team-building exercise was later run with a mixed group of staff and students. The feedback from this was very appreciative, with students saying that they would like these activities to be embedded into their degree. Sadly, due to space and timetable constraints, this was not possible.

These activities also provided the starting point for a Department-level HEA-funded project led by Ramesh (2013). This project aimed to provide students with a variety of extra-curricular activities designed to enhance the skills necessary for obtaining graduate-level jobs. The mix of new and enhanced activities included the Business Game and Maths Graduates: Where Are They Now?, advanced skills workshops, and talks from employers and professional bodies.

These various initiatives made it clear to us as a Department team that we needed more contact with employers. We also wanted to do more to celebrate graduate achievement. In order to facilitate both of these I suggested, and helped organise, a special event Greenwich Maths Talent (GMT) held after the final exams, to showcase the work of graduating students, especially their project work. Employers were invited to this to provide an opportunity for them to get to know staff and to meet students about to graduate. Initially this was a fairly small-scale event but nevertheless it enabled us to make contact with key employers and, as a direct result of this, several of our graduates obtained graduate-level jobs. There were two significant outcomes of this event. One was a collaboration between myself and one of the invited employers on a new module for final year students on data analytics (Bradshaw and Nicholas, 2017; C4). The second was the start of an expanding network of employers offering short-term placements for students. This was part of a module called the Mathematics Work Placement (MWP) which was run alongside the national work-based placement based in schools; the Undergraduate Ambassador Scheme (UAS).

When these placements started we only had a handful of students (about 10%) of the cohort taking part in these. Over recent years this has grown to over 50% of the cohort. Initially non-school-based placements took place in small accountancy firms or charities, usually found through contacts of the individual students, but under my direction they expanded to include short competitive placements and internships in investment banks, large retail corporations and actuarial firms. This has been as a direct result of academic staff networking and building relationships, improving the skillset of the students and encouraging them to apply for placements and internships. The numbers of students undertaking sandwich placements is still small but is growing; it is now around 10% of the cohort as opposed to 1% a few years ago. Waldock and Hibberd (2015) discuss the benefits of students undertaking work-based placements.

Having these events run by the Department increased student engagement with employability. Experience has shown that students are more willing to attend events promoted by tutors they know well and trust and which are advertised as particularly relevant to mathematics students than to engage with centrally-run activities which are often perceived as targeting the much larger numbers of business and computing students (Waldock and Hibberd, 2015).

4.4.2 Impact

Prior to my starting these initiatives there was no support for mathematics students regarding their future employability apart from University-wide sessions run by GET. However, students seemed reluctant to attend these and did not understand how generic advice could be applied to themselves as mathematics students.

The second year PDP assignments in the Operational Research module opened the students' eyes to the variety of careers that a mathematics degree facilitates. The first time it was set I involved GET to help deliver some of the sessions. I managed to incorporate much of the material into the academic content of the module, which was aided by the importance of soft skills for those working in Operational Research. Waldock (2011) describes several case studies where other HEIs, such as University of West of England and University of Plymouth, have embedded this sort of career awareness into the undergraduate mathematics curriculum. More recently **sigma** have published several cases studies of HEI's embedding employability into the curriculum in similar ways (Rowlett and Waldock, 2017).

The PDP assignment comprised several components. It was started early in the year which meant that most students quickly completed the first activities: a skills checklist and a set of short questions about the careers available to mathematics graduates, with a requirement to research and write about a company that interested them as a potential future employer. Some students who planned to go into teaching as a career complained that this assignment required them to research a company outside the education sector. However, when it was explained that teachers, more than anyone else, need to know about the jobs to which a mathematics degree leads, they understood the advantage of this as they agreed that they would have benefited from more advice when at school. In general, few school careers departments and maths teachers understand what you can do with a maths degree (Reiss and Mujtaba, 2016) and so providing this information to potential teachers will eventually help school students make more informed choices about A-level and degree courses.

Having completed this assignment in the first term of the second year, the students were better able to apply for sandwich placements during the second part of the second year and to look for graduate jobs during their final year. Without doubt, this raised the awareness of students of the complexity of the job application process and the need for them to develop the skills that employers are looking for in the selection process.

The philosophy behind this assignment has been disseminated at an HEA STEM conference (Bradshaw, 2014). The work also formed the basis of an hour-long employability workshop that I delivered first at a T&L conference at Greenwich and then subsequently at an HEA STEM conference in 2016. As a result, I was subsequently asked to organise and lead an HEA workshop on employability, which was hosted by Greenwich in June 2016.

The Business Game was the result of a collaboration between myself and the University Liaison Officer (ULO), Erica Tyson, at the IMA. I had been asked to judge and give feedback at an event hosted by the Business School at Greenwich. This event was run by CIMA and involved students working on small cases studies in groups, and then presenting their findings to the rest of the groups and CIMA representatives. The 'best' group obtained a small prize, and all were encouraged to take up CIMA membership. Immediately I could see possibilities here for mathematics students. Could we run an event specifically for mathematics undergraduates with a professional body that would give the students business awareness (a professional competency that most students did not obtain elsewhere) as well as evidence of other competencies (such as working with others, presenting) and also provide a slightly competitive and formal activity that would prepare them for assessment-centre activities when applying for jobs? I discussed this with Tyson, who agreed that this was a good idea. Tyson had previously worked for Rolls Royce where she had run similar activities with new trainees. We developed the business game based on a Rolls Royce training activity but adapting it to run in a shorter time and include information about the IMA and the benefits for students and graduates of membership.

The activity has changed slightly over the years, but the essential parts are still the same. Student feedback has been excellent and there is anecdotal evidence that students have found the event useful for helping them to obtain graduate-level jobs. The details of the event are described in Bradshaw (2013a) and Wolfin (2016; C1) and have been presented at the HEA STEM conference (Ramesh et al., 2014). A DVD was created about the first event and packaged so that other HEIs could easily find out how to run something similar.

Maths Graduates: Where are they now? was inspired by Walker's Calculating Careers at Manchester (Walker, 2011). In 2011 there was funding available from the National HE STEM Mathematics Curriculum Fund to put on events similar to those detailed in Waldock (2011). I made a successful application to host a similar event at Greenwich. This funding covered the travel costs of the graduates (at the first event one graduate travelled from Belgium) and catering. As a result of running this first event I started a LinkedIn group for Greenwich mathematics graduates so that we could keep in touch with them more easily in the future. I also connected with other graduates on various social media channels. Details of the event were disseminated via the National HE STEM Programme (Bradshaw, 2012a; Bradshaw, 2012b; C3). The event has led to me encouraging other Departments at the University to run similar events, resulting in improved DLHE scores.

The impact of this work on the Department of Mathematical Sciences has included the Department becoming well-known for its work on employability both in the University and in the sector. Many of the Department staff have subsequently presented at conferences on projects to do with employability (Ramesh, Bradshaw, Mann and Parrott, 2013; Ramesh et al., 2014) and contributed to articles and projects run by other institutions (Rowlett and Waldock, 2017; Judd, Knight, Lovell, Kinash and Crane 2015). Several of the projects mentioned here are used by Waldock and Hibberd (2015) as examples of good practice, showing how they are valued by leading figures in the HE mathematics community. As a result of the Showcase and meeting employers such as Ben Nicholas (GSK), the Department developed a new final year module that provides the technical skills needed by graduates seeking careers in data science and developing personal skills such as self-learning and professional development (increasingly important for graduates whose work involves fast-evolving technology) (Bradshaw and Nicholas, 2017; C4).

Personally, largely as a result of my instigating these successful initiatives in the Department of Mathematical Sciences, and the attention they received from other parts of the University, I was appointed Director of Employability for the Faculty of Architecture, Computing and Humanities in January 2015 with responsibility for overseeing employability activities in eight departments, one of which was Mathematical Sciences. In this role, I have seen the Faculty's DLHE scores for graduate outcomes increase by 10% and have overseen the embedding of new employability descriptors into the whole of the undergraduate curriculum at Greenwich. I have been asked to speak on employability at a variety of conferences and events, the most recent invitation being to deliver a keynote talk at the CETL-MSOR conference in September 2018 and a short presentation at the Heads of Mathematics (HoDoMS) conference in April 2019.

4.4.3 Critique

At an early stage of my engagement with student employability, I began to realise that it wasn't enough to embed more transferable skills into the curriculum (although that was important) but that more was needed to help our students know what jobs they could apply for, how to apply for them and provide them with the knowledge and skills required to make successful applications. In a later publication, Waldock and Hibberd (2015) refer to this as Career Management Skills giving examples of a number of Mathematics Departments (including Greenwich) doing this successfully. Recently I have seen that others have also been doing similar work (Heller, 2017; Henderson, Hooper, Line and Fowles-Sweet, 2017; Cole and Fee, 2017). Unaware of this at the time, I started educating myself by attending numerous events put on by GET and networking with as many employers as I could. I realised that there was a need for academic staff to provide information and events for students in their subject area as they had more understanding than careers advisors as to how the mathematics taught in the classroom might be used in the workplace. Also, the students had relationship and trusted their lecturing staff and so were more likely to attend events advertised by them (Bradshaw, 2017a; A1). I consulted the literature, several mathematics departments had begun working on the employability agenda, due in part to the *More Maths Grads* project (3.2.3). This growing momentum resulted in several interesting resources to consult but these concentrated on embedding skills as opposed to clearly signposted activities designed to help students make successful job applications (3.2.2). I now realise, reflecting on this, that what I was trying to do was to motivate the students to perceive the need to be proactive in order to gain appropriate employment (Dacre Pool and Sewell, 2007). I could see that my students did not know what they could do with a maths degree and, because many of them were first generation HE participants (2.1, 2.5 and 3.2.2), they had no contacts or advice regarding obtaining graduate-level opportunities.

The National HE STEM Programme funding (3.2.3) came at a particularly appropriate time for us at Greenwich in that it provided financial support and credibility to allow us to trial several ideas that we had been exploring. Running the MGWATN project inspired by Calculating Careers (Walker, 2011) enabled me to work more closely with GET who introduced me to employer competencies and mindsets, and the Adab Trust. As a result, I realised the need to make these competencies explicit in the curriculum so that students (particularly those not engaged in extra-curricular activities) had evidence they could articulate in applications. I noticed which competencies were not being addressed and put on activities to rectify this. The Business game is an example of this as it was designed to address the 'business awareness' competency (Universities UK, 2016a). There is a link between employer competencies and the graduate attributes that have been adopted by many universities in recent years (Dacre Pool, Qualter and Sewell, 2014). These attributes can be defined as the qualities, skills and understandings that a university agrees its students should develop during their programme of study. These attributes not only include, but also go beyond, the disciplinary expertise and knowledge that has traditionally formed the core of most university courses (Bowden et al., 2000).

Over the years we have added to, developed and fine-tuned these events. Inevitably some of the additions worked well, whereas others did not. For example, when I first ran the employer-endorsed PDP assignment, I offered to give students formative feedback on their CVs, job applications and cover letters. This involved rather more work than I had anticipated so the following year I reduced this to just providing formative feedback on the CVs. Latterly I harnessed the experience of staff in ECS who provided this feedback instead. Many students appreciated this opportunity to improve their work and made the most of it but some of the students were so content with the initial feedback provided that they failed to make the suggested improvements to their final submission. The idea behind this was to encourage the students to reflect critically on their own work (Wanner and Palmer, 2018). As I had experienced the positive impact of reflective practice personally I wanted my students to benefit from this as well.

Another development linked to this assignment was the introduction of interviews conducted by a recruitment company. I organised these interviews in such a way that the students were not only interviewed but also had the experience of being a member of the interview panel alongside professional recruiters. This gave them first-hand experience of seeing an interview from the perspective of the employer. All the students who participated thought it was an excellent experience. However, the turnout on the day was disappointing despite students being required to commit to attending in advance. This was potentially damaging for the Department's relationship with the recruitment company who had given a great deal of staff time to support this event. Attendance at employability workshops is addressed by Marais and Perkins (2012) who conclude that timings of events are the biggest factor in student non-attendance.

We discussed this low turnout with the students who had registered but did not turn up on the day, and it transpired that, although they realised this was an excellent opportunity and had agreed in advance to the date, they found the idea of the event too frightening. This was partly due to the fear of the unknown as they had not experienced a formal competency-based interview before. Lack of confidence and fear of the unknown in an employability context are discussed by Dacre Pool and Sewell (2007), and Beaumont, Gedye and Richardson (2016). To addresses this and help our students gain more understanding of what a competency-based interview was like, we introduced mock interviews during lecture time. To begin with we used lecturers to role play interview scenarios and then later we asked students to volunteer for the experience. However, this took significant preparation and practise time so we subsequently worked with EDU to produce a series of videos showing good and bad answers to questions (4.5.1; Bradshaw, 2015b; Bradshaw, 2015c; D3.2; D3.3). Several lecturers have used these videos in class. Role-play interview scenarios are used by Barthope and Hall (2000) as part of a course to prepare students for sandwich placement interviews with positive outcomes.

As discussed previously, students at universities like Greenwich are often first-generation participants in higher education who have a lack of social capital (2.1, 2.5 and 3.2.2). We have tried to remember this when organising events, making sure that students from all backgrounds feel comfortable so that they will attend, and providing incentives such as the opportunity to use the event in a coursework assignment.

There are HE employability models that seek to address student efficacy which have been found to be beneficial by some institutions (Dacre Pool and Sewell, 2007). Indeed, when putting in place a new employability framework for the University of Greenwich (1.1) I used this model alongside work undertaken by the CIHE and HEA (Rees, Forbes and Kubler, 2007) to produce the descriptors that subject curricula needed to address. Used alongside staff time and help, this framework ensures that students gain confidence and self-efficacy through their studies.

The initiatives discussed in this section have helped to prepare mathematics students to successfully apply for graduate-level jobs and further study opportunities. I have gone on to use my experience in the Department of Mathematical Sciences to roll out a University-wide employability framework (1.1) which has helped to raise the percentage of graduate outcomes at the University of Greenwich.

4.5 Technology in teaching (MP4's and videos)

> "July 3, 2012.
>
> What a fantastic keynote at today's EDU T&L conference. All through the day I had been worrying about the OR exam results and trying to come up with ideas as to how I could help improve students' performance next year. The students just didn't seem to be able to think through the exam questions and often gave a solution for a question that hadn't been asked. Now I think I have the answer. I will create screencasts of me working through tutorial questions so they can hear my thinking. I want them to hear the decisions I am making at each step and the different ways they can approach a question."

Soon after I began teaching Operational Research to second year students, I became concerned that the students were not understanding the material being taught. In coursework assessments and exam questions many were regurgitating solutions to problems that I had explained in class without realising that the coursework or exam questions were significantly different. Although we had put in place modules and activities to improve mathematical thinking, it was clear that we needed to specifically address the solving of unseen problems as discussed by Pritchard (2015). Devlin (2012, p.viii) says that university-level mathematics education should "develop the thinking skills that will allow [students] to solve novel problems (either practical, real-world problems or ones that arise in math or science) for which [they] don't know a standard procedure." It was these skills that I needed to instil in my students. Devlin (2012) and Mason et al. (1982) do this through a series of examples in their books that they encourage students to work through. We had given students similar examples in a new module on Mathematical Thinking and Technology (Bradshaw et al., 2012) but this was obviously not enough (4.2).

As described in the above diary excerpt, I attended a University Teaching and Learning conference where the keynote speaker shared his experience teaching school-level biology. He gave the example of teaching genetics; rather than just teaching the material in class and then setting problems for homework he created short mp4 screencasts in which he solved the questions diagrammatically for the pupils to watch at home before the class. This enabled him to focus on activities to solve different types of problems within the classroom as the children had understood the basics from the screencasts. Some of the genetic diagrams that he used looked similar to the flow charts I was trying to teach within simulation, so I could instantly see how my students might benefit from listening to similar screencasts in which I went through the worked solution, explaining my thinking at each step.

It was clear that many of our students, at the start of their second year, were not as confident or as good at independent learning as they needed to be. I wanted to do something to encourage these skills to develop during the second year as I realised that students needed them to be successful in their final year and in employment (Devlin, 2012) (3.2.1). It was important that in the second-year the students understood, rather than simply memorised, the material so that they could solve different problems rather than just the examples shown in class. Anthony (2010, p.9) found that "successful students placed more importance than failing students on . . . understanding rather than rote learning, and the ability to work independently." Encouraging independent learning is not easy, especially as the school experience of most Greenwich undergraduates appeared focused on routine assessment. This is not unusual, Devlin (2012, p.vii) says of US high school mathematics, that "the focus is primarily on mastering procedures to solve various kinds of problems" whereas at university the "focus is on learning to think in a different way". According to Walker (2015), who provides more detail around the characteristics of independent learners, Walkden and Scott (1980, p.45) identified various attitudes that they found contributed to problems experienced by undergraduate mathematics students. These were:

1. "An expectation to assimilate new ideas without mental effort;
2. A reluctance to devote time to study and to practice;
3. The lack of persistence necessary to tackle exercises of a non-trivial nature."

I realised that it was not just a "lack of persistence" but also a lack of confidence (4.4.3). As mentioned before, confidence plays a large part in one's ability to solve mathematical problems (3.2). The lecturer's role is pivotal in this, providing direction and demystifying the thinking process (Atkinson, Derry, Renkl and Wortham, 2000) and "the teacher who wishes to develop his students' ability to do problems must instil some interest for problems into their minds and give them plenty of opportunity for imitation and practise" (Polya, 1957, p.5). The problem-solving screencasts that I created were designed to address these issues by showing the students how to think through, and struggle with, a problem, eventually coming up with an appropriate and workable strategy for each case (Bradshaw, 2013b; D2). Although many staff at Greenwich were working through problems in class, students did not often hear the underlying thinking as they were focussing on noting down the 'right answer'. By providing this thinking on a video, students were able to watch it repeatedly throughout the duration of their degree and have access to other problems to practise on.

Leading on from this I have used the same technology in other modules to create screencasts on various computing techniques for dealing with data. I have used these in the teaching of Data Analytics, a new third year module designed with input from industry (4.4). This module is taught using a modification of the flipped classroom technique where the videos were created to show the students what they needed to understand and practice before each lecture (Bradshaw and Nicholas, 2017; C4).

I have also experimented with creating videos to show students how to answer competency-based interview questions and give better verbal presentations (4.4.3; Bradshaw, 2015a; Bradshaw, 2015b; Bradshaw, 2015c; Bradshaw, 2016c; D1; D3.1; D3.2; D3.3). These are available on YouTube and some students have said how helpful they have been when preparing for interviews. As the result of some internal funding at Greenwich I also led a project to create some videos on employability for students in the wider Faculty. Some of these are general, such as one on placements and one on the Faculty's skills award, whereas others are discipline-specific such as one with mathematics graduates talking about the most valuable skills they gained from their degree in preparation for their careers. This mathematics video was filmed after one of the *Maths Graduates: Where are they now?* events to take advantage of the availability of the interviewees.

4.5.1 Significance

One of the major benefits of videos and screencasts is that one can watch when you need to, pause and rewind, just pause or, of course, fast forward. Consequently, they are much more flexible than attending a lecture or a talk. The screencasts and videos I created with academic content were not intended to replace lectures, but rather to augment them to improve students' problem-solving capabilities. As Hawkes (2015) says, teaching mathematical problem solving is complex (3.2.1). One is trying to encourage students to use a range of techniques to solve a variety of problems. It is not clear to the student which techniques to use, unless they learn how to break a problem down and think through it carefully. This is summed up by Weber (2005) "A mathematical problem is a task in which it is not clear to the individual which mathematical actions should be applied, either because the situation does not immediately bring to mind the appropriate mathematical action(s) required to complete the task or because there are several plausible mathematical actions that the individual believes could be useful."

The advantage of the screencasts for these modules was that students could hear what I was thinking as I drew diagrams and solved problems and then play the recording back as often as required. This meant they could hear me explain what I was doing with a particular problem and also describe why I might do something different with a similar problem. Sometimes when I made small errors I deliberately did not remake or edit the video but rather I corrected what I had drawn or said with an explanation and carried on. I felt this was also important as it meant that students could see that everyone makes mistakes, and that this is normal and understandable, provided one is thinking and therefore able to spot mistakes at an early stage. In *Transitions in Undergraduate Mathematics* Pritchard (2015) discusses students' "anxiety and vulnerability" when embarking on a mathematics degree. He suggests that lecturers showing that they too can be fallible helps give themselves a human face showing that it is normal to make and correct errors when practising mathematics rather than be a source of anxiety to students.

The videos I created on competency-based questions showed good and bad answers to particular questions that students often seem to find difficult (4.4.3). Feedback from students showed that these were appreciated, and the videos are still being used by some lecturers. The other videos on employability give actual student and graduate reactions to different employability issues and so are helpful in encouraging other students to undertake placements or participate in activities to give them enhanced or extra skills.

4.5.2 Impact

Initially students did not understand that the mp4 screencasts in Operational Research were more useful than a pdf document providing a complete written solution. Several students still persisted in asking for solutions, showing that they were focused on the end product rather than the process. However, when they were directed to the videos, and started watching them, they saw the benefit of them. It tended to be the more conscientious students who appreciated them the most, as these were the students who were most disposed towards thinking for themselves. The students who wanted to be spoon-fed did not find the videos so useful and, sometimes, to my dismay, just fast-forwarded the screencast to the end so they could copy out the finished solution. To try and combat this problem I then delayed making the video files available for two weeks until the majority of students had at least tried the problems for themselves. This meant that most students had at least attempted the questions before they watched the screencast and thus they knew at which point they had become stuck and were therefore interested in finding out how I had progressed from that point.

The videos for the placement modules, describing how to write an academic report and prepare a reflective logbook, were also well received. These modules tended to be taken by high achieving students who had to pass a rigorous internal and external selection process to obtain a placement before being accepted on to the module. These students had become used to the medium of video from the other modules, so were comfortable using these for learning and gaining information. Although the material had already been presented in several lectures, students had not taken it all in. I found that I was receiving several emails asking the same questions about these assessments and, even with my answers, students were still not completing the assignment correctly. By providing these videos, the standard of the assignments improved considerably. The median mark for the logbook increased from 68% to 84% and the proportion of marks under 55% fell from 17% to 8%. I had not anticipated such a dramatic improvement in the work and, understandably, marks were criticised as being rather high. In subsequent years we adjusted the mark scheme to reflect the students' increased understanding, which enabled us to differentiate more appropriately between the students.

In general, as a result of including these screencasts and videos in several modules, students' performance improved with higher marks awarded despite external examiners and module moderators agreeing that the standard of the set assignments was the same: the higher marks reflecting an increase in student learning. Students have commented that they found the videos and screencasts helped increase their understanding of the topics presented.

This work has been presented at the IMA Barriers and Enablers conference (Bradshaw, 2015a; D1) and many academics from other HEIs have asked how I have made the screencasts since not all tablets work equally well for this purpose. Following this dissemination, the Department was successful in a bid for internal funding to purchase several Surface Pro tablets with Camtasia software in order to enable other staff in the Department make similar screencasts and videos which many have gone on to do.

4.5.3 Critique

As discussed in Bradshaw (2015a; D1), the use of video in HE teaching is by no means new, although modern technology makes it much easier to record videos and make them available to students, so they can be watched on mobile devices on the move as well as on laptops and pcs. Historically many great scientific and mathematics lecturers, such as Richard Feynman, had their classes videoed to increase their impact (Filmer, 2014). Many of these recordings are now available online as a resource for anyone interested in learning or teaching science. The Open University is a great example of an institution that survived on the medium of televised lectures, the recordings of which are still in existence (Wilson, 2015b). Nowadays there are numerous free online courses by providers such as Coursera (Coursera, 2014) and Udacity (Udacity, 2014) as well as scientific information videos from individuals such as Destin Sandlin (Smarter Every Day, 2018), Mehdi Sadaghdar (ElectroBOOM, 2018) and Derek Muller (Veritasium, 2018). They each have a very different presentation style and yet their audiences often overlap. Many of the videos they create are termed to be “receptive” as they are often viewed by a passive audience (Klay and Ketskin, 2012). However, there are other online courses (often requiring a subscription) where learners have to complete tasks to obtain certificates requiring an active audience in order to achieve a set goal.

Many HE practitioners have attempted to create their own videos and screencasts to help their learners learn actively. Such practitioners have a variety of motivations. Fahlberg, a pioneer of problem-based mathscasts, states that the benefits of these include students seeing and hearing the lecturer think through a problem, accessing the material when they want to which enables them to understand the process and not just the result (Fahlberg, Fahlberg-Stojanovska and MacNeil, 2007). Other providers see the main benefit as improving study skills and attainment (McCombs and Liu, 2007; Alpay and Gulati, 2010). Students themselves have made favourable comments; in particular that it enables them to have control over their own learning (Loch, Gill and Croft, 2012). A practical research project by Jordan, Loch, Lowe, Mestel and Wilkins (2012) on whether using short screencasts improved student learning of mathematics found that their students thought that screencasts helped their understanding of mathematical techniques and the study concluded that they were a “powerful tool to support student learning” (Jordan et al., 2012). Loch et al. (2012)

found that within maths support students cited improved understanding and reasoning as a major benefit of using them.

Whilst there is little in the literature concerning the downside of creating short videos and screencasts, it is worth mentioning that the time factor involved is not insignificant. Creating five minutes of a screencast can take several hours, once one has factored in the scripting and equipment setup and the recording of video and sound simultaneously. I tend to record every video in one take so, when I make an error, I pause and redo that section in the same take rather than create the video in small chunks that I later splice together. This means that a 5-minute recording often ends up being 15 minutes before the errors and pauses are edited out. It is very difficult, with all the other pressures on academic staff, to give sufficient time to projects like this. The quality of my videos would have certainly been improved had I had more time to spend on them.

Choosing the right software is another issue. This is discussed in more detail in Bradshaw (2015a; D1). With technology changing so rapidly there are now more apps that enable screen-capture on iPads and tablets and much better phone cameras that allow videos to be created without the need for expensive kit. Producing videos and screencasts will continue to become easier and faster, thus enabling more learning resources to be readily available to students which will, in turn, mean that more students will expect them.

4.6 Summary

This chapter has provided a detailed commentary on my public works. The autoethnographical and reflective approach has shown that my motivation for these has stemmed from my experience as a student and my desire to improve the student experience especially transition. This is often when students struggle and, if not supported appropriately, students may fail or at the very least not perform as well as they should.

In the transition from school to university, students might fail to engage and drop out of their studies. The Maths Arcade is designed to help students through this period and also through the transition from first year to second year; a key time when some students find the work increases in complexity and they fail to make necessary adjustments for this.

The transition from university to graduate job is another area where students, especially those with little prior family experience of higher education, often falter. The projects I have put in place have been designed to help students prepare for this earlier in their studies. The PDP assignment takes place in the second year, the events like *Maths Graduates: Where are they now*? and the IMA

Business Game are targeted to second year students as is attending the Tomorrow's Mathematicians Today conference, although many of the presenters are final year students.

The screencasts and videos have all been motivated by my desire to improve students' understanding and thus improve their learning experience. In Operational Research, these were designed to help the students think, and learn how to problem-solve on their own. On the other hand, in the final year placement modules, videos were designed to help students better understand what was expected of them and thus increase their attainment. In the new final year Data Analytics module, they served the purpose of encouraging the students to assimilate and practice a technique that I did then not need to teach in lecture time, so the lectures could be used for other activities and employer talks. They were also designed to encourage self-study. The videos on job interviews provided the students with examples of situations that they had not experienced and so increased their understanding of unfamiliar situations not dissimilar from the other videos.

All of this work has been disseminated in the mathematics and STEM HE sector and has been met with favourable feedback. Students have said that my work has increased their confidence, given them more examples to use in job interviews, and generally made them more employable.

5. Conclusion

"*Transition to another situation and phase of education or employment will always cause some problems for students or any of us. We must aim to reduce the likelihood of these problems, diagnose those that remain, and offer support to those affected*." Appleby and Cox (2002, p.16).

This chapter seeks to sum up the personal and professional discoveries and lessons I have learned from undertaking research around my public works as part of this professional doctorate. Using autoethnography and critical reflection it identifies key themes which I hope will be used by those in HE to identify other projects to improve the student experience and help students through the various transitions they will encounter during their degree programme. It concludes by looking at the future for HE mathematics departments.

5.1 Revelations and lessons learned

Taking a critically reflective look at my journey to date, from someone with one A-level in home economics to a senior university academic and now a data scientist, has enabled me to see the value of all the steps along the way and the importance I have placed on networking and taking on new opportunities and challenges. These activities and networks have enabled me to transition between the different stages of my career. Using an autoethnographic approach I can see that, in part, I have tried to provide students with similar opportunities for networking and gaining experience and skills, thus allowing them to make equally successful transitions.

5.1.1 Personal

On the personal side, I have discovered what it is about my background that has contributed to my instigating these various initiatives. My rather negative school experience, coloured by a debilitating speech impediment, enabled me to increase my understanding of those students with personal problems and/or from a non-standard educational background (2.1 and 2.2). This led me to set up initiatives to help them, rather than dismiss them as not being serious students as some other academics might be tempted to do (2.6.1). Whilst I am aware of unconscious bias (1.2), which I acknowledge probably does cause me to discriminate against some groups of people more than I realise, I think that my general desire to help those whom society has discriminated against, has been one of the central motivations behind my public works. The disadvantaged groups on which this commentary has provided fresh insight are mature students, students with non-standard entry qualifications, first generation entrants to HE, and those affected by dysfluency (2.1; 2.4; 2.5). In particular, I was previously unaware of the literature that suggests stammering can produce resilience and that there was evidence for the theory that mature students possess better study skills, despite experiencing both of these in practice. My reflections on this have led me to take up membership of the British Stammering Association (BSA) and attend their biannual conference. This is a relationship that I see as becoming more important over time, with the possibility of mentoring stammering young adults at work and giving motivational talks at events for those who stammer.

5.1.2 Professional

On the professional side, I have understood more about different research methodologies, the time and value of the networks I have created, and my own modus operandi. Whilst I have long been a firm advocate of reflection, both personally and when instructing students, this research journey has made me more aware of its benefits to individuals in the workplace. I have brought this knowledge into my current working practice and the ways in which I manage my team at work.

The greatest revelation and surprise to me was realising that, when I was an undergraduate at Greenwich, there was a great deal of “employability provision” already in the curriculum when I had genuinely thought there was none. However, the problem was that it had neither been made explicit nor discussed in the context of careers, so, even the best and most discerning of students did not recognise it. The provision was particularly in the form of diverse assessments which enabled students to work in groups, deliver presentations, write reports for different audiences, learn industry-relevant software and programming techniques, and gain work experience. These are all skills and opportunities that are obviously important for student employability but on their own students can, and did, misinterpret them. There was no mention of what careers were available to those with a mathematics degree, no talks from industry professionals or graduates, no information about where you could go for help and advice, and no explanation as to how all these soft skills enabled you to progress to the next level of your career.

Even the best students are, understandably, focussed on obtaining a good degree. Indeed, staff encourage this. So, it is unsurprising that students will not see implicit provision unless it is made clear to them that it is there and how they need to use it to their advantage. I think many institutions, individual Departments and teaching teams need to understand that it is not enough to include these opportunities to gain skills within the curriculum, but that it is also necessary to articulate this, so that the student hears it. I did this at Department level by encouraging students to write reflective accounts on the employability content, so I knew that they had heard the message I was providing. At University-level I encouraged module leaders to tell students why particular assessment methods were being used and what employability provision could be obtained from each module. They did this verbally in class and also in written format on the virtual learning environment for their module or in the module handbook. Recent graduate outcomes (2017) have certainly improved across the institution which is, I would like to think, partly due to this initiative (1.1; 3.3.4; 4.4.2).

5.2 Key themes

It was not until I started talking about and reflecting on my public works that I realised that the common link was that of transition. Further critical reflection has caused me to see how my works fit into the current HE landscape and the lessons that could be learnt from their instigation. This has enabled me to see beyond the actual activities themselves, and identify the underlying strategies which have contributed to their success. It is these strategies, which I think are particularly important for others to be aware of. Many HE Departments and individuals have replicated, and might want to continue to replicate, some of my public works. Whilst this is potentially beneficial, I am aware that in contrasting institutions, with different groups of students they might be less appropriate. However, the strategies and motivations behind the works are important and can be used as foundations from which to grow new activities, better suited to a different institution and cohort of students. Without undertaking this research, I would not have seen or understood this.

My public works demonstrate new innovative ways of helping students through potentially traumatic times of transition. They have all made a huge impact on the lives of students at Greenwich and several of them, such as the Maths Arcade and TMT, have impacted the lives of students elsewhere. Most universities, and indeed subject groups, are looking for strategies to improve or sustain their TEF rating. This means that there is now a focus for all HEIs on how best to enhance the student experience and improve retention. The overarching theme of transition, and the motivations behind my works, are transferable, at least for mathematics students, and this is what I hope other individuals and institutions can learn from the work and research that I have undertaken.

5.2.1 Easing transition into HE

The Maths Arcade was primarily established to help students transition from school to university (4.2). The key feature of this work is that it is an activity that promotes staff/student interaction, enabling students to see staff as “normal” and accessible. It encourages students to make early friendships and feel part of a community. Any activity that does this might have the same transitional benefit as the Maths Arcade, so can be used to help students in other disciplines who are not specifically interested in developing mathematical thinking through playing strategy board games.

5.2.2 Easing transition between years

Establishing friendships and creating community are also useful for easing transition between year groups. However, to help students cope with the academic jump between years the emphasis on encouraging students to develop independent learning and problem-solving skills has been important. I have shown that the earlier that students get acclimatised to this way of working, the more successful they become and the easier they will find it to make the jump between year groups, or to simply take on a new module with a different lecturer who has a different style of teaching

5.2.3 Improving transition out of HE

The other area of transition is that of leaving HE and moving into employment or further study. As with the previous periods of transition, students find spending time with staff, and friendships with their peers valuable, but there are other aspects that can be generalised and therefore be used to establish further events and projects. Students need to prepare for this transition before it happens, so input about the world of work should take place in the first or second year of a degree in order for students to apply for placements as well as graduate-level jobs. Students need to be encouraged to find out for themselves, what they want to do career-wise, who they want to work for or where they want to study. However, some students will shy away from doing this so, making these activities part of an assessment will help encourage participation. Practising any job selection task is useful; whether that is having a mock interview, completing a job application form or taking part in a simulated assessment centre activity. Networking activities, where students have opportunities to meet and talk to professionals from a variety of industries, are also helpful and desirable.

5.3 Future

The success of my public works at the University of Greenwich and elsewhere, demonstrate their significance for those in HE. If I had remained in academia, I would be seeking to use this research to influence my own practice as well as that of my colleagues. However, my move into industry does not mean that this will be unused. At Sainsbury's Argos I am part of the Commercial Supply Talent Group that is looking for new and innovative ways to recruit the right graduates into an analytical career in retail. I am the only member of the group to have recent experience of HE and a network of graduates across the country to tap into. The skills that I have learned through perceiving problems in a system (albeit education) and coming up with strategies to resolve them are just as useful in industry as in HE. Despite this, I see my move into industry as a "gap" period in my career rather than something I plan to do long-term. Indeed, I think it is useful for academics to gain first-hand experience of the industries where their graduates work, as this will make them more useful to the students they teach in the future. It is also worth mentioning that I have had more invitations to speak at academic conferences (CETL-MSOR 2018, TMT 2019, HoDoMS 2019) since leaving HE than I had before, showing that I am able to add value to HE whilst working in industry.

This is an exciting time for action and practitioner-based research in HE mathematics education. A workshop held at the University of Birmingham in memory of Professor John Blake (3.2.3) looked at the future of HE mathematics education in the UK and invited senior leaders in the field to share their vision for “next steps” (Grove and Kyle, 2018). Interestingly many of these focused on ensuring that mathematics graduates have appropriate skills for the future job market and are very relevant to the areas that I have been working in. Professor Chris Linton recommended taking a fresh look at the undergraduate mathematics curriculum to make sure it was still relevant. Stephen Hibberd suggested increasing the number of vocational mathematics modules and assessments within the HE mathematics curriculum to provide transferable skills. This was echoed by Jeremy Levesley who proposed setting new forms of assessment to help graduates succeed in the workplace. The only non-academic speaker, Gary Brown from the ONS, discussed the necessity for providing graduates with training in statistics and data manipulation to ensure they have the skills necessary for the “data revolution”. Joe Kyle’s “blue-sky thinking” revolved around increasing students’ ability and understanding of problem-solving and developing their skills to form appropriate judgements as to “what is real and ‘fake’, but more importantly to ask questions and challenge perceptions of what is valid and reliable”. Tony Croft emphasised the need to continue to address the “Mathematics Problem” by educating senior university managers and improving university mathematics teaching and Michael Grove urged the community to provide opportunities for undertaking and disseminating new research in HE mathematics Teaching and Learning (Grove and Kyle, 2018). I reiterated these potential next steps to a large group of Heads of Mathematics Departments at the HoDoMS conference in April 2019 (3.2.1).

I believe that I have demonstrated that my works have contributed to these next steps, and, in the words of John Blake, I have helped to provide “leadership in learning and teaching” contributing to the preservation of the MSOR legacy (Blake, 2012, p.35). My works have all been used extensively at Greenwich and many have been used or adapted for use at other institutions such as Sheffield Hallam University. The undergraduate conference, Tomorrow’s Mathematicians Today has impacted many students from a wide variety of institutions that otherwise would not have had the opportunity to present their research or listen to others’ research at that stage of their careers.

These works, coupled with the underlying motivations and key themes that I have identified, will hopefully enable other institutions to innovate and instigate new activities and events designed to help students gain the most benefit from their university experience. I look forward to building on these works in a new role and to discovering how they have inspired future academics to help further cohorts of students.

References

Abdulwahed, M., Jaworski, B. and Crawford, A., 2012. Innovative approaches to teaching mathematics in higher education: a review and critique. *Nordic Studies in Mathematics Education*, 17(2), pp.49-68.

Abramsky, J., Porkess, R., McColl, J.H. and Sangwin, C., 2001. Curriculum 2000. *MSOR Connections*, 1(3), pp.32-45.

Alcock, L., 2013. *How to Study for a Mathematics Degree*. Oxford, UK: Oxford University Press.

Allen-Collinson, J and Hockey, J., 2008. Autoethnography as 'valid' methodology? A Study of disrupted identity narratives. *The International Journal of Interdisciplinary Social Sciences*, 3(6), pp.209-217.

Alpay, E. and Gulati, S., 2010. Student-led podcasting for engineering education. *European Journal of Engineering Education*, 35 (4), pp.415-427.

AMSP, 2019. Advanced Mathematics Support Programme. [online] Available at: https://amsp.org.uk/ [Accessed: 5 May 2019].

Anderson, L., 2006. Analytic autoethnography. *Journal of Contemporary Ethnography*, 35(4), pp.373-395.

Anthony, G., 2000. Factors influencing students' success in mathematics. *International Journal of Mathematical Education in Science and Technology*, 31(1), pp.3-14.

Appleby, J and Cox, W., 2002. The transition to higher education. In: P. Khan and J. Kyle, eds. *Effective Learning and Teaching in Mathematics and its Applications*. London, UK: Kogan Page. Ch.1.

Artess, J., Hooley, T. and Mellors-Bourne J., 2017. *Employability: A review of the literature 2012 to 2016.* York, UK: Higher Education Academy.

Ashwin, P. and McVitty, D., 2015. The Meanings of Student Engagement: Implications for Policies and Practices. In: A. Curaj, Matei L., Pricopie R., Salmi J., Scott P., eds. *The European Higher Education Area*. [online] Cham, Switzerland: Springer. Available at: https://link.springer.com/book/10.1007/978-3-319-20877-0 [Accessed: 6 May 2019].

Astin, A.W., 1984. Student Involvement: A Development Theory for Higher Education. *Journal of College Student Development*, 40(5), pp.518-529.

Atkinson, R.K., Derry, S.J., Renkl, A. and Wrotham, D., 2000. Learning from Examples: Instructional principals from the worked examples research. *Review of Educational Research*, 70(2), pp.181-214.

Augar, P., 2019. Independent panel report to the Review of Post-18 Education and Funding. London, UK: HMSO. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/805127/Review_of_post_18_education_and_funding.pdf [Accessed: 30 May 2019].

Badger, M.S., Sangwin, C.J., Hawkes, T.O., Burn, R.P., Mason, J. and Pope, S., 2019. *Teaching Problem Solving in Undergraduate Mathematics*. [pdf] Birmingham, UK: HE STEM. Available at: https://www.birmingham.ac.uk/Documents/college-eps/college/stem/teaching-problem-solving-undergraduate-mathematics.pdf [Accessed: 28 April 2019].

Baird, J., Ebner, K. and Pinot de Moira, A., 2003. *Student choice of study in Curriculum 2000*. Manchester: AQA Centre for Education Research and Policy, [online] Available at: https://cerp.aqa.org.uk/research-library/student-choice-study-curriculum-2000 [Accessed 8 September2018].

Barbe, W. and Milone, M,N., 1981. What we know about modality strengths. *Educational Leadership. Association for Supervision and Curriculum Development*, pp.378–380.

Barthope, S. and Hall, M., 2006. A collaborative approach to placement preparation and career planning for university students: a case study. *Journal of Vocational Education & Training*, 52(2), pp.165-175.

Batistic, S. and Tymon, A., 2017. Networking behaviour, graduate employability: a social capital perspective. *Education + Training*, 59(4), pp.374-388.

Baxter, A. and Britton, C., 2011. Risk, identity and change: Becoming a mature student. *International Studies in Sociology of Education*, 11(1), pp.87-104.

Beaumont, E., Gedye, S. and Richardson, S., 2016. ‘Am I employable?’: Understanding students' employability confidence and their perceived barriers to gaining employment. *Journal of Hospitality, Leisure, Sport & Tourism Education,* 19, pp.1-9.

Beneito, P., Bosca, J.E. and Ferri, J., 2018. Tuition fees and student effort at university. *Economics of Education Review.* 64, pp.114-128.

Blake, J.R., 2012. Reflections from a past Director (2000-8). *MSOR Connections*, 12(2), pp.34-35.

Boaler, J., 2016. *Mathematical Mindsets: Unleashing Students' Potential through Creative Math, Inspiring Messages and Innovative Teaching*. San Francisco, USA: Jossey Bass.

Bochner, A.P., 1984. The functions of human communication in interpersonal bonding. In: C.C. Arnold and J.W. Bowers, eds. *Handbook of rhetorical and communication theory.* Thousand Oaks, USA: Sage. pp.21-41.

Bochner, A.P. and Ellis, C., 1992. Personal narratives as a social approach to interpersonal communication. *Communication Theory*, 2(2), pp.242-269.

Bochner, A.P. and Ellis, C., 1996. Introduction: Taking Ethnography into the Twenty-First Century. J*ournal of Contemporary Ethnography,* 25(1), pp.3-5.

Bolton, P., 2012. *Education: Historical statistics*. (SN/SG/4252). London, UK: House of Commons.

Bolton, P., 2014. *HE in England from 2012: Student numbers*. (SN/SG/6205). London, UK: House of Commons.

Bond, P., 2018. *The Era of Mathematics: An Independent Review of Knowledge Exchange in the Mathematical Sciences* [online] Available at: https://epsrc.ukri.org/newsevents/pubs/era-of-maths/ [Accessed: 17 May 2019].

Bowden, J., Hart, G., King, B., Trigwell, K. and Watts, O., 2000. Generic Capabilities of ATN University Graduates, Australian Government Department of Education, Training and Youth Affairs, Canberra.

Boyd, R. D. and Fales A., 1983. Reflective learning: key to learning from experience. *Journal of Humanistic Psychology*, 23(2), pp.99-117.

Boyer Commission on Educating Undergraduates in the Research University, 1998. *Reinventing Undergraduate Education: A Blueprint for America's Research Universities.* Stony Brook, NY, USA: State University of New York.

Bradshaw, N., 2009. Tribute to Triplets: A model for successful group work. *Compass: The Journal of Learning and Teaching at the University of Greenwich*, 1(1), pp.21-23. ISSN 2044-0081.

Bradshaw, N., 2010. Undergraduate Mathematics Conference report: Tomorrow's Mathematicians Today. *Mathematics Today*, 46(2), p.74.

Bradshaw, N., 2011a. Making Maths Graduates More Employable: an enhanced role for tutors. Birmingham, UK: National HE STEM. Available at: https://www.birmingham.ac.uk/university/colleges/eps/STEM/National-HE-STEM-Programme/higher-level-skills-curriculum-development.aspx [Accessed 15 September 2018].

Bradshaw, N., 2011b. The University of Greenwich Maths Arcade. *MSOR Connections*, 11(3), pp.26-29. ISSN 1473-4869.

Bradshaw, N., 2012a. Maths Graduates: Where are they now? In: P. Rowlett, ed. 2012. *Further Work Developing Graduate Skills in HE Mathematics Programmes.* Birmingham, UK: HESTEM, pp.10-11.

Bradshaw, N., 2012b. Maths Graduates: Where are they now? In: E. Chadwick and M. Singh, eds. 2012. *Employer Engagement: Case studies for adoption in HEI Mathematical Sciences.* Birmingham, UK: HESTEM. Ch.5. Available at: https://www.birmingham.ac.uk/Documents/college-eps/college/stem/Employer-Engagement-Case-Studies-for-adoption-in-HEI-Mathematical-Sciences.pdf [Accessed: 5 July 2018].

Bradshaw, N., 2012c. Making Maths Graduates More Employable: an enhanced role for tutors. In: E. Chadwick and M. Singh, eds. 2012. *Employer Engagement: Case studies for adoption in HEI Mathematical Sciences.* Birmingham, UK: HESTEM. Ch.4. Available at: https://www.birmingham.ac.uk/Documents/college-eps/college/stem/Employer-Engagement-Case-Studies-for-adoption-in-HEI-Mathematical-Sciences.pdf [Accessed: 5 July 2018].

Bradshaw, N., 2012d. *Noel Ann Bradshaw - Making Maths Grads Employable*. National HESTEM Programme. [video online] Available at: https://vimeo.com/48071876 [Accessed 15 September 2018].

Bradshaw, N., 2012e. Undergraduates Speak Out! Undergraduate Mathematics Conference: Tomorrow's Mathematicians Today. *Compass: The Journal of Learning and Teaching at the University of Greenwich,* 3(4), pp.21-25. ISSN 2044-0081.

Bradshaw, N., 2013a. IMA Business Game, *Mathematics Today*, 49(1), p.28.

Bradshaw, N., 2013b. Encouraging Students to Think Using Online Learning Resources. *University of Greenwich Teaching and Learning Conference*. London July 2013. Available at: https://showtime.gre.ac.uk/index.php/edu/sp/schedConf/presentations [Accessed 15 September 2018].

Bradshaw, N., 2014. Employer-endorsed employability assessment: an assignment delivered in an operational research course to second year mathematics students. In: Higher Education Academy, *STEM Annual Conference 2014*. Edinburgh, 2014. York, UK: HEA.

Bradshaw, N., 2015a. The use of video and mathscasts to engage and support the learner and promote mathematical thinking. In: Institute of Mathematics and its Applications, *IMA International*

Conference on Barriers and Enablers to Learning Maths: Enhancing Learning and Teaching for All Learners. Glasgow, 10-12 June 2015. Southend: IMA.

Bradshaw, N., 2015b. *Good job interviews*. [video online]. Available at: https://www.youtube.com/playlist?list=PL5ybYlTaCtx4rlmkTOdQZy-2vVtp03nFg [Accessed 12 March 2016].

Bradshaw, N., 2015c. *Poor job interviews*. [video online]. Available at: https://www.youtube.com/playlist?list=PL5ybYlTaCtx6W5nSkT1cCehJssjha0iix [Accessed 12 March 2016].

Bradshaw, N., 2016a. Flipping Employability: Discovering how to further embed employability into the mathematics curriculum. Presented at The Higher Education Academy STEM conference, Nottingham, 28-29 January 2016. Available at: https://www.heacademy.ac.uk/system/files/downloads/2.6_nabradshaw-flipping_employability.pdf [Accessed 15 September 2018].

Bradshaw, N., ed.,2016b. *MSOR Connections*, 14(3).

Bradshaw, N., 2016c. Creating videos to assist students' understanding of the graduate recruitment process. *Compass: Journal of Learning and Teaching*, 8(12). Available at: https://journals.gre.ac.uk/index.php/compass/article/view/274/319 [Accessed 15 September 2018].

Bradshaw, N., 2017a, The Maths Arcade: A tool for supporting and stretching mathematics undergraduates. In: L.N. Wood and Y.A. Breyer, eds. *Success in Higher Education: Transitions to, within and from University.* Singapore: Springer. Ch.6.

Bradshaw, N., 2017b, Florence Nightingale (1820–1910): A Pioneer of Data Visualisation. In: J.L. Beery, S.J. Greenwald, J.A. Jensen-Vallin and M.B. Mast eds. *Women in Mathematics,* Association for Women in Mathematics Series, vol 10. Cham, Switzerland: Springer. Ch. 11.

Bradshaw, N., ed.,2018. *MSOR Connections*, 15(1).

Bradshaw, N., George, E., Lakin, S., Mann, T. and Ramesh, N.I., 2012. Breadth versus depth: a new first year module providing an introduction to the range of mathematics. In: CETL-MSOR, *CETL-MSOR Conference 2011,* Coventry University, UK, 5-6 September 2011. Birmingham: The Maths, Stats and OR Network, pp.28-32.

Bradshaw, N. and Mann, T., 2019. The University of Greenwich at the Old Royal Naval College. In: R. Flood and T. Mann, eds. *Mathematics at the Meridian*. Boca Raton, FL, USA: Taylor and Francis. Ch.11.

Bradshaw, N. and Nicholas, B., 2017. A combination of industry collaboration and flipped classroom to increase learners' confidence and skillset. In: CETL-MSOR, *CETL-MSOR Conference 2016*: *A Brave New World.* Loughborough University, 6-7 September 2016. Birmingham: **sigma**. pp.10-16.

Bradshaw, N., Parrott, K., Lakin, S., Mann T. and Sharp, M., 2012. In: C. Robinson, ed., 2012. *Student-centred Approaches in Mathematics*. Birmingham, UK: MSOR Network. Available at: http://www.mathcentre.ac.uk/resources/uploaded/Studentcentered.pdf [Accessed 30 April 2019].

Bradshaw, N. and Richardson, K., 2013. Book Reviews for Mathematics Undergraduates: an assignment to enhance reading and writing skills essential for today's workplace and to promote collaboration between library and academic staff. *Compass: The Journal of Learning and Teaching at the University of Greenwich,* 4(7), pp.1-6.

Bradshaw, N. and Rowlett P., eds., 2012. *Maths Arcade: stretching and supporting mathematical thinking*. Birmingham, UK: MSOR Network. Available at: http://www.mathcentre.ac.uk/resources/uploaded/mathsarcade.pdf [Accessed 9 September 2018].

British Society for the History of Mathematics, 2018. [online] Available at: http://www.bshm.ac.uk/ [Accessed 12 July 2018].

Brookfield, S.D., 1998. Critically Reflective Practice. *The Journal of Continuing Education in the Health Professions*, 18, pp.197–205.

Brookfield, S.D., 2015. Critical reflection as doctoral education. *New Directions for Adult and Continuing Education,* 2015(147), pp.15-23.

Broom, D., 1989. Exam abuse harms students' chances; AS level examination. *The Times*. 23 November.

Bunce, L., Baird, A. and Jones, S.E., 2016. The Student-as-Consumer Approach in Higher Education and its Effect on Academic Performance. *Studies in Higher Education*, 42(11), pp.1958-1978.

Burkhardt, H. and Bell, A., 2007. Problem Solving in the United Kingdom. *International Journal on Mathematics Education*, 39(5-6), pp.395–403.

Business, Innovation and Skills Committee, 2016. *The Teaching Excellence Framework: Assessing quality in Higher Education*. (Third Report of Session 2015–16) London: The Stationary Office Ltd.

Cadwallader, S. and Tremain, K., 2013. *How policy formation and implementation interacts with risks to high stakes qualifications*. Manchester, AQA Centre for Education Research and Practice.

Challis, N., 2015. Group work within undergraduate mathematics. In: M. Grove, A.C. Croft, J. Kyle and D.A. Lawson, eds. *Transitions in Undergraduate Mathematics Education*. Birmingham: University of Birmingham. Ch.7.

Challis, N., Gretton, H., Huston, K. and Neill, N., 2002. Developing transferable skills: preparation for employment. In: P. Kahn and J. Kyle, eds. *Effective Teaching and Learning in Mathematics & its Applications*. London, UK: Kogan. pp.79-91.

Challis, N., Robinson, M. and Thomlinson, M., 2009. "Employability" skills in mathematical courses. *MSOR Connections*, 9(3), pp.38-41.

Cheng, E., 2015. *How to Bake Pi: An Edible Exploration of the Mathematics of Mathematics*. New York: Basic Books.

Cheng, E., 2018. *The Art of Logic: How to Make Sense in a World that Doesn't*. London: Profile Books.

Citizen Maths, 2014. Citizen Maths. [online] Available at: https://citizenmaths.com/ Accessed 4 April 2015.

Cleaver, E., Lintern, M. and McLinden M.,, eds, *Teaching and Learning in Higher Education: Disciplinary Approaches to Educational Enquiry*. 2nd edition, London, UK. Sage.

Cole, J. and Fee, K., 2017. Employability 2 – module for second-year engineering students. In: P. Rowlett and J. Waldock, eds. *Employability development for HE mathematics and statistics: Case studies of successful practice*. Sheffield, UK: Sheffield Hallam University on behalf of **sigma**.

Cornock, C., 2015. Maths Arcade at Sheffield Hallam University: Developments made in a new space. *MSOR Connections*, 14(1), pp.54–61.

Council for the Mathematical Sciences, 2018. [online] Available at: http://www.cms.ac.uk/objectives [Accessed 13 July 2018].

Courant, R., Robbins, H. and Stewart, I., 1996. *What Is Mathematics? An Elementary Approach to Ideas and Methods.* 2nd ed. Oxford, UK: Oxford University Press.

Coursera, 2014. Coursera Online Courses. [online] Available at: https://www.coursera.org/ [Accessed 27 October 2014].

Crawford, K., 2009. Continuing Professional Development in Higher Education: Voices from Below. PhD. University of Lincoln. Available at: http://eprints.lincoln.ac.uk/2146/1/Crawford-Ed%28D%29Thesis-CPDinHE-FINAL%28Sept09%29.pdf [Accessed: 11 May 2019]

Croft, A.C., Duah, F. and Loch, L., 2013. “I’m worried about the correctness”: undergraduate students as producers of mathematical explanations for their peers – lecturer and student perceptions, *International Journal of Mathematical Education in Science and Technology*, 44(7), pp.1045-1055.

Croft, A.C. and Grove, M., 2015. Progression within mathematics degree programmes. In: M. Grove, A.C. Croft, J. Kyle and D.A. Lawson, eds. *Transitions in Undergraduate Mathematics Education*. Birmingham, UK: University of Birmingham. Ch.13.

Croft, A.C., Lawson, D., Hawkes, T., Grove, M., Bowers, D. and Petrie, M., 2014. **sigma** – a network working! *Mathematics Today.* 50(1).

Crozier, G., Reay, D., Clayton, J., Colliander, L. and Grinstead J., 2008. Different strokes for different folks: diverse students in diverse institutions – experiences of higher education. In: *Research Papers in Education,* 23(2). Available at: http://www.tandfonline.com/doi/abs/10.1080/02671520802048703 [Accessed 26 July 2017].

Dacre Pool, L., Sewell, P.J., 2007. The key to employability: developing a practical model of graduate employability, *Education and Training*, 49(4), pp.277-289. https://doi.org/10.1108/00400910710754435

Dacre Pool, L., Qualter, P. and Sewell, P.J., 2014. Exploring the factor structure of the CareerEDGE employability development profile, *Education and Training*, 56(4), pp.303-313, https://doi.org/10.1108/ET-01-2013-0009

Daly, I., Bourgaize, J. and Vernitski, A., 2019. Mathematical mindsets increase student motivation: Evidence from the EEG. *Trends in Neuroscience and Education*, 15, pp.18-28.

Deloitte, 2012. *Measuring the Economic Benefits of Mathematical Science Research in the UK*. London, UK: Deloitte.

Department for Business Innovation and Skills, 2011. *Students at the heart of the system*. (Cm8122). London, UK: The Stationary Office Ltd.

Department for Business, Innovation and Skills, 2015. *Fulfilling our Potential: Teaching Excellence, Social Mobility and Student Choice*. London, UK: The Stationary Office Ltd.

Department for Business, Innovation and Skills, 2016. *Higher education: success as a knowledge economy - white paper*. London, UK: The Stationary Office Ltd.

Desai, S., 2017. *The School of Mathematics and Statistics' Undergraduate Research Conference* [online] Available at: http://www.mcs.st-and.ac.uk/UMRC/UGConference/index.html [Accessed: 28 April 2019].

Devlin, K., 2012. *Introduction to Mathematical thinking*. Petaluma, CA, USA: Keith Devlin

Doyle, E., Mullins, M., and Cunningham, M., 2010. Research ethics in a Business School context: The establishment of a review committee and the primary issues of concern. *Journal of Academic Ethics*, 8, pp.43-66.

Dweck, C.S. and Molden, D.C., 2005. Self theories and their impact on competence motivation and acquisition. In: A.J. Elliot and C.S. Dweck, eds. *Handbook of Competence and Motivation*, New York, USA: Guildford Press. pp.122-140.

Easson, V. and McOwan, P.M., 2015. Using Mathematics to Motivate and Inspire Future Generations of Learners. In: M. Grove, A.C. Croft, J. Kyle and D.A. Lawson, eds. *Transitions in Undergraduate Mathematics Education*. Birmingham, UK: University of Birmingham.

ELBA, 2016a. *What is Eagles.* [online] Available at: https://elba-1.org.uk/what-we-do/employment-works/eagles-graduate-scheme/ [Accessed 13 June 2018].

ELBA, 2016a. *London Works recruitment.* [online] Available at: https://elba-1.org.uk/what-we-do/employment-works/london-works-recruitment-agency/ [Accessed 13 June 2018].

ElectroBOOM, 2018. Hilarious Electricity Fails. [YouTube] Available at: https://www.youtube.com/watch?v=3XVtUUtfjJE [Accessed 5 July 2018].

Ellis, C., 2007. Telling Secrets, Revealing Lives: Relational Ethics in Research With Intimate Others. *Qualitative Inquiry*, 13(1), pp.3-29.

Ellis, N., 2017. *Tomorrow's Mathematicians Today Conference Report* [online] Available at: https://www2.mmu.ac.uk/media/mmuacuk/content/documents/school-of-computing-mathematics-and-digital-technology/tmt17/TMT-2017-Conference-Report-v2.pdf [Accessed: 18 May 2019].

Ellis, C., Adams, T.E. and Bochner, A.P., 2010. Autoethnography: An Overview [40 paragraphs]. *Qualitative Social Research*, 12(1), Art. 10. Available at: http://nbn-resolving.de/urn:nbn:de:0114-fqs1101108 [Accessed 15 September 2018].

Ernest, P. 1996. Popularization: myths, mass media and modernism. In: A. J. Bishop ed. *The International Handbook of Mathematics Education,* Dordrecht: Kluwer Academic. pp.785-817.

Evans, E., 1990. AS examinations: a user's perspective. In: *Advanced Supplementary examination 1989: the first examination cycle: a review. A report of two working conferences for GCE chief examiners, moderators and board officers.* Manchester, 24–25 February and 17–18 March 1990. London: School Examinations and Assessment Council.

Fahlberg, T., Fahlberg-Stojanovska, L. and MacNeil, G., 2007. Whiteboard Math Movies. Teaching Mathematics and its Applications, 26(1), pp.17-22.

Fauvel, J. and Grey, J., 1987. *The History of Mathematics: An Open University Course Reader.* Basingstoke, UK: Palgrave Macmillan.

Fenton, A., 2011. The National HE STEM Programme. *MSOR Connections*, 11(3), p.3.

Filmer, J., 2014. *Now, You Can Watch the Feynman Lectures Online For Free.* [online] Available at: https://futurism.com/the-feynman-lectures-are-now-online-and-free/ [Accessed 5 July 2018].

Fook, J., 2007. Reflective Practice and Critical Reflection. In: J. Lishman, ed., *Handbook for Practice Learning in Social Work and Social Care*, 2nd ed: Knowledge and Theory. Jessica Kingsley, pp. 363-75.

Foster, E., Lawther, S., Keenan, C., Bates, N., Currant, B. and Lefever, R. 2012. *The HERE Project Toolkit: A resource for programme teams interested in improving student engagement and retention.* Nottingham, UK: Nottingham Trent University, Paul Hamlyn Foundation and Higher Education Funding Council for England.

Frenkel, E., 2013. *Love and Math*. New York, USA: Basic Books.

Further and Higher Education Act 1992. (c.13). London: HMSO.

Fry, H., Ketteridge, S. and Marshall, S. eds., 2009. *A Handbook for Teaching and Learning in Higher Education.* 3rd ed. Oxford: Routledge.

Gale, D., 1979. The Game of Hex and the Brouwer Fixed-Point Theorem. *The American Mathematical Monthly*, 86(10), pp.818-827. doi:10.2307/2320146.

Gardner, M., 1959. *The Scientific American Book of Mathematical Puzzles and Diversions*, New York, USA: Simon & Schuster.

Gillard, J., 2017. The National Student Survey: Lessons from looking at 10 years of data. In: CETL-MSOR and Teaching Mathematics and its Applications, *Mathematics Education beyond 16: Pathways and Transitions a conference of the IMA*, University of Birmingham. 10 - 12 July 2017, **sigma**.

Goodman, A., Joshi, H., Nasim, B. and Tyler, C., 2015. *Social and Emotional Skills in Childhood and their Long-Term effects on Adult Life*. London, UK: UCL Institute of Education.

Goodyear, P. and Ellis, R.A., 2007. The development of epistemic fluency: Learning to think for living. In: A. Brew and J. Sachs, eds. *Transforming a university: The scholarship of teaching and learning in practice*. Sydney: Sydney University Press, pp.57-68.

Goodyear, P. and Zenios, M., 2007. Discussion, collaborative knowledge work and epistemic fluency. *British Journal of Educational Studies.* 55(4), pp.351–68.

Gormon, S., 2007. Managing Research Ethics A head-on Collision? In: A. Campbell and S. Groundwater-Smith, eds. *An Ethical Approach to Practitioner Research*, Oxon: Routledge. 109 Perspectives on Pedagogy and Practice.

Grove, J., 2017. THE Teaching Survey 2017: results and analysis in The Times Higher Education 16/02/2017. Available at https://www.timeshighereducation.com/features/the-teaching-survey-2017-results-and-analysis#survey-answer [Accessed 05 April 2018].

Grove, M., 2013. *The National HE STEM Programme Final Report*, Birmingham, UK: The University of Birmingham.

Grove, M., Brown, G., Croft, A.C., Hibberd, S., Kyle, J., Levesley, J. and Linton, C., 2017. Where next for mathematics education in higher education? *MSOR Connections*, 16(2), pp.3-15. http://dx.doi.org/10.21100/msor.v16i2

Grove, M., Coft, A.C., Kyle, J. and Lawson, D. 2015. *Transitions in Undergraduate Mathematics Education*. Birmingham: The University of Birmingham.

Grove, M. and Kyle, J., 2018 In: E. Cleaver, M. Lintern, and M. McLinden, eds, *Teaching and Learning in Higher Education: Disciplinary Approaches to Educational Enquiry*. 2nd edition, London, UK. Sage.

Gunsalus, C. K., 2004. The nanny state meets the inner lawyer: overegulating while underprotecting human participants in research. *Ethics & Behavior*, 14(4), pp.369-382.

Gurung, R.A.R. and Schwartz, B.M., 2009. *Optimizing Teaching and Learning Practicing Pedagogical Research*. Chichester, UK: Wiley-Blackwell.

Hack, K., 2015. Does pedagogic research warrant independent ethical review by a research ethics committee? In: *Perspectives on Pedagogy and Practice*, 6, pp.105-111.

Harvey, L., 2000. New Realities: The relationship between higher education and employment. *Tertiary Education and Management*, 28(4), pp.3-17.

Hawkes, T., 2015. Problem Solving in a Mathematics Degree. In: M. Grove, A.C. Croft, J. Kyle and D.A. Lawson, eds. *Transitions in Undergraduate Mathematics Education*. Birmingham, UK: University of Birmingham. Ch.8.

Hayes, C. and Fulton, J., 2015. Autoethnography as a method of facilitating critical reflexivity for professional doctorate students. *Journal of Learning Development in Higher Education*, 8(2015). [online] Available at: https://journal.aldinhe.ac.uk/index.php/jldhe/article/view/237 [Accessed 11 April 2019].

Healey, M. and Jenkins, A., 2009. *Developing undergraduate research and inquiry*. York: Higher Education Academy.

HEFCE, 2018. *About HEFCE* [online] Available at: https://webarchive.nationalarchives.gov.uk/20180319114234/http://www.hefce.ac.uk/about/ [Accessed: 25 January 2018].

Heller, M., 2017. School of Mathematics, Statistics & Actuarial Science Employability Programme. In: P. Rowlett and J. Waldock, eds. *Employability development for HE mathematics and statistics: Case studies of successful practice*. Sheffield, UK: Sheffield Hallam University on behalf of **sigma**.

Henderson, K., Hooper, A., Line, T. and Fowles-Sweet, W., 2017. Employability sessions for Mathematics students. In: P. Rowlett and J. Waldock, eds. *Employability development for HE mathematics and statistics: Case studies of successful practice*. Sheffield, UK: Sheffield Hallam University on behalf of **sigma**.

HESA, 2018a. Figure 14 - HE student enrolments by subject area and sex 2012/13 to 2016/17. [online] Available at: https://www.hesa.ac.uk/news/11-01-2018/sfr247-higher-education-student-statistics/subjects [Accessed: 15 September 2018].

HESA, 2018b. *Statutory Framework*. [online] Available at: https://www.hesa.ac.uk/about/regulation/statutory [Accessed 15 September 2018].

HESA, 2018c. *Experts in UK higher education data and analysis, and the designated data body for England.* [online] Available at: https://www.hesa.ac.uk/ [Accessed 15 September 2018].

HESA, 2018d. *Graduate Outcomes*. [online] Available at: https://www.hesa.ac.uk/innovation/outcomes [Accessed 22 September 2018].

Hibberd, S. and Grove, M., 2009. Developing graduate and employability skills within a mathematical sciences programme. *MSOR Connections*, 9(2), pp.33-39.

Higher Education Academy, 2015. *Framework for embedding employability in higher education*. [online] Available at: https://www.heacademy.ac.uk/knowledge-hub/framework-embedding-employability-higher-education [Accessed 13 July 2018].

Hilderbrand, A.J., 2019. Undergraduate Math Conferences. [online] Available at: https://faculty.math.illinois.edu/~hildebr/ugresearch/conferences.html [Accessed 28 April 2019].

House of Lords, Lords Select Committee Science and Technology, 2012. *Higher Education in Science, Technology, Engineering and Mathematics (STEM) subjects*. London: TSO (The Stationery Office).

Houston, K., 2009. *How to Think Like a Mathematician*. Cambridge UK: Cambridge University Press.

IMA, 2018. The Institute *of Mathematics and its Applications.* [online] Available at: https://ima.org.uk/ [Accessed 14 June 2018]

Johnston, B., 2003. The Shape of Research in the Field of Higher Education and Graduate Employment: some issues. *Society for Research into Higher Education,* 28(4), pp.413-426, DOI: 10.1080/0307507032000122260

Joint Mathematical Council of the United Kingdom, 2018. [online] Available at: https://www.jmc.org.uk/ [Accessed 13 July 2018].

Jordan, C., Loch, B., Lowe, T., Mestel, B. and Wilkins, C., 2012. Do short screencasts improve student learning of mathematics? MSOR Connections, 12(1), pp.11-14.

Judd, M., Knight, C., Lovell, C., Kinash, S. and Crane, L. 2015. Case Studies to enhance graduate employability: Generalist disciplines. *Learning and Teaching papers*. Paper 110. Available at: http://epublications.bond.edu.au/tls/110 [Accessed 5 July 2018].

Justice, C., Rice, J., Warry, W., Inglis, S., Miller, S. and Sammon. S., 2007. Inquiry in higher education: Reflections and directions on course design and teaching methods. *Innovation in Higher Education* 31 pp.201–14.

Karp, D., 1996. *Speaking of sadness*. New York, USA: Oxford University Press.

Katz, V. J., 2004. *A History of Mathematics*. 2nd ed. London, UK: Pearson.

Kettley, N., 2007. The past, present and future of widening participation research. *British Journal of Sociology of Education,* 28(3), pp. 333-347.

Klay, R., and Kletskin, I., 2012. Evaluating the use of problem-based video podcasts to teach mathematics in higher education. *Computers & Education*, 59(2012), pp.619–627.

Knowles, M. and Associates, 1984. *Andragogy in Action*, Houston, TX: Gulf Publishing.

Kolb, D.A., 1984. *Experiential learning: Experience as the source of learning and development*. New Jersey, USA: Prentice-Hall.

Kolb, D.A. and Fry, R.E., 1974. Toward an applied theory of experiential learning. MIT Alfred P. Sloan School of Management.

Kyle, J., 2015. The changing nature of mathematics within UK higher education. In: M. Grove, A.C. Croft, J. Kyle and D.A. Lawson, eds. *Transitions in Undergraduate Mathematics Education*. Birmingham: University of Birmingham. Ch.1.

Lawson, D.A., 2015. Mathematics Support at the Transition to University. In: M. Grove, A.C. Croft, J. Kyle and D.A. Lawson, eds. Transitions in Undergraduate Mathematics Education. Birmingham: University of Birmingham. Ch.4.

Le Roux, C.S., 2017. Exploring rigour in autoethnographic research, *International Journal of Social Research Methodology*, 20(2), pp.195-207, DOI: 10.1080/13645579.2016.1140965.

Leithwood, C. and O'Connell, P., 2003. It's a struggle: the construction of the 'new student' in higher education. *Journal of Education Policy*, 18(6), pp. 597-615.

Lee, S., Lord, K., Dudzic, S. and Stripp, C., 2018. *Investigating the impact of curriculum and funding changes on Level 3 mathematics uptake*. [pdf] Trowbridge, UK: MEI. Available at: http://mei.org.uk/files/pdf/MEI-national-survey-ES.pdf [Accessed on 24 August 2018].

Lindsay, G. and Dockrell, J., 2000. The Behaviour and Self-Esteem of Children with Specific Speech and Language Difficulties. *British Journal of Educational Psychology* 70, pp.583-601.

Loch, B., Gill, O. and Croft, A.C., 2012. Contemplating mathematics support with online mathscasts. *ANZIAM Journal Electronic Supplement*, Sydney, Australia: EMAC, pp.C561-C575.

London Mathematical Society, 1995. *Tackling the Mathematics Problem*, London, UK: London Mathematical Society. Available at: http://mei.org.uk/files/pdf/Tackling_the_Mathematics_Problem.pdf [Accessed 15 September 2018].

London Mathematical Society, 2018. [online] https://www.lms.ac.uk/ [Accessed 12 July 2018].

Longden, B., 2012. "Bearing Down" on Student Non-Completion: Implications and Consequences for English Higher Education, *J.College Student Retention*, 14(1), pp.117-147.

Lord, K. and Lee, S., Transition into Higher Education: Universities influence on schools provision for AS/A level Maths and Further Maths. In: CETL-MSOR and Teaching Mathematics and its Applications, *Mathematics Education beyond 16: Pathways and Transitions a conference of the IMA*, University of Birmingham. 10 - 12 July 2017, **sigma**.

Mann, T., 2011. Ideas Exchange: HE Mathematics Curriculum Innovation. *MSOR Connections*, 11(3), pp.54-55.

Mandela, N., 1994. *Long Walk to Freedom*. UK: Little Brown.

Marais, D. and Perkins, J., 2012. Enhancing employability through self-assessment. *Procedia - Social and Behavioral Sciences,* 46, pp.4356 – 4362.

Maso, L., 2001. Phenomenology and ethnography. In: P. Atkinson, A. Coffey, S. Delamont, J. Lofland, and L. Lofland eds. *Handbook of ethnography*. Thousand Oaks, USA: Sage. pp.136-144.

Mason, J.H., 2002. *Mathematics Teaching Practice: A guide for university and college lecturers*. Chichester, UK: Horwood/Open University.

Mason, J.H., Burton, L., and Stacey, K., 1982. *Thinking Mathematically*. Harlow, UK: Pearson Education.

Mathematical Association of America (MAA), 2019. Regional Undergradaute Mathematics Conferences. [online] Available At: https://www.maa.org/regional-undergraduate-mathematics-conferences-2 [Accessed: 28 April 2019].

Mathematics Education and Industry, 2015. *Changing the structure of AS/A levels in Mathematics and Further Mathematics*, An MEI Discussion Paper. Available at: http://mei.org.uk/files/pdf/models_2015_3.pdf [Accessed: 15 September 2018].

Maths Careers, 2018. [online] Available at: http://www.mathscareers.org.uk/ [Accessed 15 September 2018].

Maths Careers, 2019. *How to Choose a Maths Degree* [online] Available at: https://www.mathscareers.org.uk/article/how-to-choose-a-maths-degree/ [Accessed: 18 May 2019].

Mccaig, C., 2015. The impact of the changing English higher education marketplace on widening participation and fair access: evidence from a discourse analysis of access agreements. *Widening Participation and Lifelong Learning*, 17, pp.5-22.

McCombs, S. and Liu, Y., 2007. The efficacy of podcasting technology in instructional delivery. *International Journal of Technology in Teaching and Learning*, 3(2), pp.123–134.

McIlveen, P., 2008. Autoethnography as a method for reflexive research and practice in vocational psychology. *Australian Journal of Career Development*, 17(2), pp.13-20.

MillionPlus, 2018. *Forgotten Learners: Building a system that works for mature students*. London, UK: Million Plus.

More or Less, 2017. Investigating the numbers in the news. [Radio programme] BBC, Radio 4, 5 May 2017, Available at: https://www.bbc.co.uk/programmes/b08ns2lw [Accessed 15 September].

Moreau, M. and Leithwood, C., 2006. Graduates' employment and the discourse of employability: a critical analysis. *Journal of Education and Work*, 19(4), pp.305-324.

MSOR Connections, 2018. *MSOR Connections*. [online] Available at: https://journals.gre.ac.uk/index.php/msor/index [Accessed 5 July 2018].

Muller, J.Z., 2018. *The tyranny of metrics*. Princeton, USA: Princeton University Press.

The National Committee of Inquiry into Higher Education, 1997. (Dearing Report). London, UK: Her Majesty's Stationery Office.

National Research Council, 2013. *The Mathematical Sciences in 2025*. Washington DC, USA: The National Academies Press. https://doi.org/10.17226/15269.

Ngunjiri, F.W., Hernandez, K.C. and Chang, H. 2010. Living Autoethnography: Connecting Life and Research. *Journal of Research Practice,* 6(1).

O'Donoghue, J. and Fitzmaurice, O., 2015. Embedding a Scholarly Element into Your Teaching. In: M. Grove, A.C. Croft, J. Kyle and D.A. Lawson, eds. Transitions in Undergraduate Mathematics Education. Birmingham: University of Birmingham. Ch.19.

Office for Students, 2018. *Unistats.* [online] Available at: https://unistats.ac.uk/ [Accessed 12 July 2018].

Office of National Statistics, 2016. *How has the student population changed?* [online] Available at: http://visual.ons.gov.uk/how-has-the-student-population-changed/ [Accessed: 10 June 2017].

Operational Research Society, 2018. [online] http://www.theorsociety.com/ [Accessed 12 July 2018].

Pennington, J.L., 2007. Silence in the classroom/whispers in the halls: autoethnography as pedagogy in White pre-service teacher education. Race Ethnicity and Education, 10(1), pp.93-113.

Pevy, L., 2010. The Portsmouth University Maths Café: Making a Virtue of Necessity. In: C.M.Marr and M.J.Grove, eds. *Responding to the Mathematics Problem: The Implementation of Institutional Support Mechanisms*. Birmingham, UK: MSOR Network. Available at: http://www.mathcentre.ac.uk/resources/uploaded/mathssupportvolumefinal.pdf [Accessed 5 July 2018].

Pierce, B., 1882. Linear Associative Algebra. New York, USA: D. Van Nostrand.

Pillay, D., Naicker, I. and Pithouse-Morgan, K, 2016 Writing Academic Autoethnographies: Imagination, Serendipity and Creative Interactions In: D. Pillay, I. Naicker and K. Pithouse-Morgan, eds. *Academic Autoethnographies Inside Teaching in Higher Education*. Rotterdam: Sense publishers.

Pitard, J., 2016. Using Vignettes Within Autoethnography to Explore Layers of Cross-Cultural Awareness as a Teacher. *Forum Qualitative Sozialforschung / Forum: Qualitative Social Research*, 17(1), Art. 11 [online] Available at: http://nbn-resolving.de/urn:nbn:de:0114-fqs1601119 [Accessed 25 April 2019].

Plutarch, n.d. *On Listening to Lectures*. Translated by F. C. Babbitt., 1927 Vol. I of the Loeb Classical Library edition. Available at: http://penelope.uchicago.edu/Thayer/E/Roman/Texts/Plutarch/Moralia/De_auditu*.html [Accessed 15 September 2018].

Polya, G., 1957. *How to solve it: A new aspect of mathematical method*. 2nd ed. New Jersey, USA: Princeton Science Library.

Porkess, R., 2001. Curriculum 2000. *MSOR Connections*, 1(3)

Pritchard, D., 2015. Lectures and Transition: from bottles to bonfires? In: M. Grove, T. Croft, J. Kyle and D.A. Lawson eds. *Transitions in Undergraduate Mathematics Education*. Birmingham, UK: University of Birmingham.

Prospects, 2018. *What do Graduates Do?* ed L.Greaves [online] Available through: https://luminate.prospects.ac.uk/what-do-graduates-do?utm_source=prospects&utm_medium=referral&utm_campaign=wcidwmd [Accessed: 22 April 2019].

QAA, 2015. Subject benchmark statement: Mathematics, statistics and operational research. Gloucester, UK: Quality Assurance Agency for Higher Education.

Ramesh, N., Bradshaw, N., Mann, T. and Parrott, K., 2013. *Professional body and employer engagement to enhance employability of mathematics students*. HEA STEM Annual Conference, University of Birmingham, Birmingham, 17-18 April, 2013.

Ramesh, N., Mann, T. and Parrott, K., 2014. Extracurricular activities to enhance employment outcomes of Mathematics graduates. HEA STEM [online] Available at: https://www.heacademy.ac.uk/system/files/resources/MSOR-142-P.pdf [Accessed 14 June 2018].

Ramirez, G., Hooper, S.Y, Kersting, N.B., Ferguson, R. and Yeager, D., 2018. Teacher Math Anxiety Relates to Adolescent Students' Math Achievement, *AERA Open*, 4(1), pp.1–13.

Reay, D., Ball, S. and David, M. 2002. It's taken me a long time but I'll get there in the end': Mature students on access courses and higher education choice. *British Educational Research Journal*, 28(1), pp.5–19.

Reay, D., Crozier, G., and Clayton, J., 2010. Fitting in' or 'standing out': working class students in UK higher education. *British Educational Research Journal,* iFirst Article, pp.1–18 Available: https://www.educ.cam.ac.uk/people/staff/reay/FittinginBERJ2010.pdf [Accessed 15 September 2018].

Rees, C., Forbes P. and Kubler, B., 2007*. Student Employability Profiles: A guide for higher education practitioners*. York, UK: The Higher Education Academy.

Regan, J. A., Baldwin, M. A. and Peters, L., 2012. Ethical issues in pedagogic research. *Journal of Pedagogic Development*, 2(3), pp. 44-54

Reiss, M.J. and Mujtaba, T., 2016. Should we embed careers education in STEM lessons?, *The Curriculum Journal*, 28:1, pp.137-150, DOI: 10.1080/09585176.2016.1261718.

Richardson, J.T.E., 2006. Mature students in higher education: A literature survey on approaches to studying. *Studies in Higher Education*, 19:3, pp.309-325, DOI: 10.1080/03075079412331381900.

Roberts, S., 2015a. A Life in Games: The Playful Genius of John Conway. Quanta Magazine. Available at: https://www.quantamagazine.org/john-conways-life-in-games-20150828/ [Accessed 28 July 2017].

Roberts, S., 2015b. *The Curious Mind of John Conway*. New York, USA: Bloomsbury USA.

Robinson, M., Challis, N.V. and Thomlinson, M., 2010a. *Maths at University - Reflections on experience, practice and provision*. More Maths Grads.

Robinson, M., Challis, N.V. and Thomlinson, M., 2010b. *Maths at University: Start to finish – your guide to maths at university*. London, UK: More Maths Grads Project and the LMS.

Rowlett, P., 2011. Acting on recommendations from the HE Mathematics Curriculum Summit, *MSOR Connections*, 11(3), pp.4-7.

Rowlett, P., 2012a. In: C. Robinson, ed., 2012. *Student-centred Approaches in Mathematics*. Birmingham, UK: MSOR Network. Available at: http://www.mathcentre.ac.uk/resources/uploaded/Studentcentered.pdf [Accessed 30 April 2019].

Rowlett, P., 2012b, *Summary of work in mathematical sciences HE curriculum innovation*, Birmingham: HESTEM.

Rowlett, P., 2013. A Modification of Bradshaw's Method of Group Allocation When You Do Not Know the Students. *MSOR Connections*, 13(2), pp.43-50.

Rowlett, P., 2015. Developing Strategic and Mathematical Thinking via Game Play: Programming to Investigate a Risky Strategy for Quarto In: *The Mathematics Enthusiast* 12(1). Available at: https://scholarworks.umt.edu/cgi/viewcontent.cgi?article=1334&context=tme [Accessed 7 June 2018].

Rowlett, P., 2017. Recording small group interaction to encourage reflection on group work. In: P. Rowlett and J. Waldock, eds. *Employability development for HE mathematics and statistics: Case studies of successful practice*. Sheffield, UK: Sheffield Hallam University on behalf of **sigma**.

Rowlett, P. and Waldock, J. 2017. *Employability Development for HE mathematics and statistics: case studies of successful practice*. Sheffield: Sheffield Hallam University.

Rowlett, P., Webster, K., Bradshaw, N. and Hind, J., 2019. Evaluation of the Maths Arcade initiative at five U.K. universities. In: *The Mathematics Enthusiast.* 16(1&2), Article 23.

Roy, D., Borin, P. and Kustra, E., 2003, *What Is Unique about Inquiry Courses?* [online]. Center for Leadership in Learning, McMaster University, Canada. Available at: http://cll.mcmaster.ca/resources/misc/whats_unique_about_inquiry.html [Accessed 19 April 2019].

Royal Society, 2019. The Royal Society Advisory Committee on Mathematics Education [online] Available at: https://royalsociety.org/topics-policy/education-skills/mathematics-education/royal-society-acme/ [Accessed: 11 May 2019].

Russell, B.,1917. *Mysticism and Logic and other essays.* London, UK: George Allen and Unwin Ltd.

Savage, M.D. and Hawkes, T., 2000. *Measuring the Mathematics Problem*. London, UK: Engineering Council.

Scott, P., 1995. *The Meanings of Mass Higher Education,* Buckingham, UK: SHRE and Open University Press.

Searle, J. and Barmby, P., 2012. *Evaluation Report on the Realistic Mathematics Education Pilot Project at Manchester Metropolitan University*. Durham, UK: Durham University.

Select Committee on Education and Employment, 2001. *Higher Education: Student Retention*. Sixth Report. London: House of Commons.

Smarter Every Day, 2018. SmarterEveryDay YouTube channel. [YouTube] Available at: https://www.youtube.com/user/destinws2 [Accessed 5 July 2018].

Smith, A., 2004. *Making Mathematics Count: The report of Professor Adrian Smith's Inquiry into Post-14 Mathematics Education*. London, UK: TSO (The Stationary Office).

Sodhi, M. and Son, B., 2007. Math Modelling: What Skills do Employers Want in Industry? In: C. Haines, P. Galbraith, W. Blum and S. Khan, eds. 2007. *Education, Engineering and Economics–ICTMA 12,* Chichester, UK: Horwood Publishing Ltd. Ch. 4.

Spence, C., 2019. 'Judgement' versus 'metrics' in higher education management. *Higher Education*, 77, pp.761–775.

Spronken-Smith, R., and Walker, R., 2010. Can inquiry-based learning strengthen the links between teaching and disciplinary practice? *Studies in Higher Education,* 35(6), pp.723–40.

Sriraman, B. and English, L., 2010. *Theories of Mathematics Education Seeking New Frontiers*. Berlin, Germany: Springer.

Steele, N., 2007. *Keeping HE Maths where it Counts: The decline in provision of mathematics sciences courses with more moderate entry requirements: drivers and implications*. London, UK: The Council for the Mathematical Sciences. [online] Available at: https://www.lms.ac.uk/sites/lms.ac.uk/files/Mathematics/Policy_repors/2007%20Steele_Report_Keeping%20Maths%20where%20it%20Counts_Final.pdf [Accessed 12 July 2018]

Stein, D., 2000. Teaching Critical Reflection. *Myths and Realities,* No. 7.

STEM Learning, 2009. More Maths Grads. Available at: https://www.stem.org.uk/elibrary/collection/2779 [Accessed 10 June 2017].

Stewart, I., 2006, *Letters to a Young Mathematician*. New York, USA: Basic Books.

Stripp, C., 2017. Reflections on the uptake of AS/A level Maths, AS/A level Further Maths and Core Maths. *NCETM Charlie's Angels blog* [blog] Available at: https://www.ncetm.org.uk/resources/50919 [Accessed: 4 May 2019].

Sutch, T., Zanini, N. and Benton, T., 2015. *A level reform: implications for subject uptake*. Cambridge Assessment Research Report. Cambridge, UK: Cambridge Assessment.

Taber, K.S., 2016. What is wrong with 'practice' papers*, Chemistry Education Research and Practice*, 17, pp.639-645.

Tall, D., 2004. Introducing Three Worlds of Mathematics. *For the Learning of Mathematics*, 23 (3), pp. 29–33.

Temple, P., Callender, C., Grove L. and Kersh, N., 2014. *Managing the student experience in a shifting higher education landscape*. York, UK: Higher Education Academy.

Thomas, L., 2002. Student retention in higher education: the role of institutional habitus. *Journal of Education Policy*, 17(4), pp.423-442.

Thomas, L. and Quinn, J., 2006. First Generation Entry into Higher Education. Maidenhead, UK: Open University Press.

Toman, N., Leahy, J. and Caldwell, J., 2005. Surviving diversity? Student progression in a post 1992 Institution. Paper presented at the 35th Annual SCUTREA Conference July 5-July 7 2005, University of Sussex, UK.

Tomlinson, M., 2002. Inquiry into A Level Standards [online] Available at: http://news.bbc.co.uk/1/shared/spl/hi/education/02/tomlinson_report/pdf/final_report.pdf [Accessed: 4 May 2019].

Tomorrow's Mathematicians Today, 2016. *Quotes from past TMT conferences*. [online] Available at: http://mathsoc.cms.gre.ac.uk/tmt/Quotes.html [Accessed 5 July 2018].

Tomorrow's Mathematicians Today, 2018. *Origins of TMT*. [online] Available at: https://sites.google.com/site/imatmt2019/origins-of-tmt [Accessed 15 September 2018].

Tracy, S.J., 2010. Qualitative quality: Eight big-tent criteria for excellent qualitative research. Qualitative Inquiry, 16, pp.837–851.

Trahar, S., 2013. Autoethnographic Journeys in Learning and Teaching in Higher Education. *European Educational Research Journal,* 12(3), pp.367-375.

Trowler, V., 2010. *Student engagement literature review*, Available at: https://www.heacademy.ac.uk/system/files/studentengagementliteraturereview_1.pdf [Accessed 13 June 2018].

Trowler, P. and Trowler, V., 2010. Student engagement evidence summary. Available at: http://eprints.lancs.ac. uk/61680/1/Deliverable_2._Evidence_Summary._Nov_2010.pdf [Accessed 28 July 2017].

Trueman, M. and Hartley, J., 1996. A Comparison between the Time-Management Skills and Academic Performance of Mature and Traditional-Entry University Students. *Higher Education*, 32(2), pp.199-215.

Tschannenn-Moran, M. and Hoy, W. A., 2001. Teacher-Efficacy: Capturing an Elusive Construct. *Teaching and Teacher Education*, 17,pp. 783-805.

Turnbull, S., 2010. *A Guide to UK League Tables in Higher Education*. Oxford, UK: Higher Education Policy Institute.

Udacity, 2014. Udacity. [online] Available at: https://www.udacity.com/lp/homebranded?gclid=CjwKEAjw2reiBRCaobK3udOj-Q4SJACXWyYmH8nkmRHZT5nT_34ZqRQJhlD3cPbgah-7FzqjsrazhoC30rw_wcB [Accessed 27 October 2014].

Underdal, A., 2010. Implications of the change from elite to mass or multi-purpose institutions. In: E. De Corte and J.E. Fenstad, eds. *Wenner-Gren International Series, volume 85 From Information to Knowledge; from Knowledge to Wisdom*. Chapter 6, pp.45-51. London: Portland Press.

Universities UK, 2016a. *Higher Education in England: Provision, Skills and Graduates* [pdf] London: Universities UK. Available at: [Accessed: 30 April 2019].

Universities UK, 2016b. *Patterns and Trends in University Education* [pdf] London: Universities UK. Available at: http://www.universitiesuk.ac.uk/policy-and-analysis/reports/Documents/2015/patterns-and-trends-2015.pdf [Accessed: 10 June 2017].

Universities UK, 2018. *Growth and Choice In University Admissions*, [pdf] London: Universities UK. Available at: https://www.universitiesuk.ac.uk/policy-and-analysis/reports/Documents/2018/growth-and-choice-in-university-admissions-final.pdf [Accessed: 5 May 2019].

Universities UK, 2019. *The Future of the TEF Report to the Independent Reviewer* [pdf] London: Universities UK. Available at: https://www.universitiesuk.ac.uk/policy-and-analysis/reports/Documents/2019/future-of-the-tef-independent-reviewer.pdf [Accessed: 18 April 2019].

University of Greenwich, 2018, *Greenwich in The Times and Sunday Times Good University Guide 2018*. [online] Available at: https://www.gre.ac.uk/articles/archive/public-relations/greenwich-the-times-sunday-times-good-university-guide-2018 [Accessed 15 September 2018].

Veritasium, 2018. *Veritasium an element of truth*. [YouTube] Available at: https://www.youtube.com/channel/UCHnyfMqiRRG1u-2MsSQLbXA [Accessed 5 July 2018]

Vorderman, C., Budd, C., Dunne, R., Rahman-Hart, P. and Porkess, R., 2011. (Vorderman Report). *A World-class Mathematics Education for All our Young People*. London, UK: HMG.

Wakeley, P., 2014. Why Chalk Talks in Mathematics Education. *MSOR Connections* 4(1), p.8.

Waldock, J., 2011. Developing graduate skills in HE Mathematics Programmes: Case studies of successful practice. Birmingham, UK: HESTEM.

Waldock, J. and Hibberd, S., 2015. Employability for the workplace. In: M. Grove, A.C. Croft, J. Kyle and D.A. Lawson, eds. *Transitions in Undergraduate Mathematics Education*. Birmingham, UK: University of Birmingham.

Waldock, J., Rowlett, P., Cornock, C., Robinson, M. and Bartholomew, H., 2017. The role of informal learning spaces in enhancing student engagement with mathematical sciences. *International Journal of Mathematical Education in Science and Technology*, 48 (4), pp.587-602.

Walkden, F. and Scott, M.R., 1980. Aspects of Mathematical Education. *International Journal of Mathematical Education in Science and Technology*, 11(1), pp.45-53.

Walker, L., 2011. Calculating Careers. In: J. Waldock ed. *Developing Graduate Skills in HE Mathematics Programmes*. Birmingham, USA: HESTEM. pp.12-13.

Walker, L., 2015. Enabling students to become independent learners. In: M. Grove, T. Croft, J. Kyle and D.A. Lawson, eds. *Transitions in Undergraduate Mathematics Education*. Birmingham, UK: University of Birmingham. Ch.6.

Wanner T. and Palmer E., 2018. Formative self-and peer assessment for improved student learning: the crucial factors of design, teacher participation and feedback. *Assessment & Evaluation in Higher Education*, 43(7), pp.1032-1047.

Warren, S., 2016. Struggling for visibility in higher education: caught between neoliberalism 'out there' and 'in here' – an autoethnographic account. *Journal of Education Policy*, 1(14).

Weber, K., 2005. Problem solving, proving and learning: The relationship between problem solving processes and learning opportunities in the activity of proof construction. *Journal of Mathematical Behaviour*, 24, pp.351-360.

Wells, D., 2012. *Games and Mathematics Subtle Connections*. New York, USA: Cambridge University Press.

Whitehead J., 1989. Creating a living educational theory from questions of the kind, 'how do I improve my practice?', *Cambridge Journal of Education*, 19(1), pp.41–52

Williams, J., 2015. Mathematics Education and the Transition into Higher Education. In: M. Grove, A.C. Croft, J. Kyle and D.A. Lawson, eds. *Transitions in Undergraduate Mathematics Education*. Birmingham: University of Birmingham. Ch.2.

Willingham, D.T., Hughes, E.M. and Dobolyi, D.G., 2015. The Scientific Status of Learning Styles Theories. *Teaching of Psychology,* 42(3), pp. 266-271 DOI: 10.1177/0098628315589505.

Wilson, R., 2015a. Editorial. MSOR Connections, 14(1), pp.2-3.

Wilson, R.J., 2015b. History of Mathematics Film Day. *BSHM Bulletin: Journal of the History of Mathematics*, 30(1), Birmingham, UK: Taylor and Francis. p.79.

Wolfin, S., 2016. IMA business Game at University of Greenwich. *MSOR Connections*, 14(2), pp.34–36.

Wong, B. and Chiu, Y.T., 2019. Let me entertain you: the ambivalent role of university lecturers as educators and performers, 71(2), pp. 218-233.

Wood, L.N. and Breyer, Y.A., eds. 2018. *Success in Higher Education: Transitions to, within and from University.* Singapore: Springer.

Wright, P., 1996. Mass higher education and the search for standards, *Higher Education Quarterly*, 50(1), pp.71-85.

Wyse, D., Brown, C., Oliver, S. and Poblete, X., 2018. *The BERA Close-To-Practice Research Project.* London: British Educational Research Association, Available at: https://www.bera.ac.uk/researchers-resources/publications/british-education-research-journal [Accessed 6 May 2019].

Yorke, M. and Knight, P., 2006. *Embedding employability into the curriculum.* York, UK: Higher Education Academy.

Appendices

Evidence of public works.

A. Maths Arcade

A1. Case study on the Maths Arcade.

Bradshaw, N., 2017, The Maths Arcade: A tool for supporting and stretching mathematics undergraduates. In: L.N. Wood and Y,A, Breyer, eds. *Success in Higher Education: Transitions to, within and from University.* Singapore: Springer. Ch.6.

Chapter 6
The Maths Arcade: A Tool for Supporting and Stretching Mathematics Undergraduates

Noel-Ann Bradshaw

Abstract The Maths Arcade is an activity which aims simultaneously to support those university mathematics learners who are having difficulties, stretch more confident learners, and encourage the development of a staff-student mathematical community. The first Maths Arcade was set up at the University of Greenwich in September 2010, funded initially by a University grant for innovative teaching and later by the Mathematical Sciences Curriculum Innovation Fund of the UK National Higher Education STEM Program. The idea was developed and disseminated through conference presentations and workshops, and this has led to Maths Arcades being initiated in at least ten other UK universities, with interest from other academic disciplines such as business, computing, and engineering. This chapter discusses the motivation behind the initial idea as well as some of the different implementations. It also shows how this activity has been used to support and retain students, and how it has contributed to student success both academically and in terms of graduates' progression into appropriate professional careers.

Keywords At-risk students · Employment outcomes · Faculty-student interaction · STEM · Peer-mentoring · Belonging

Context

Students in England can study for a degree-level qualification in a variety of institutions. This can be a university, an institution conducted by a higher education corporation, an institution designated as eligible to receive support from funds administered by the Higher Education Funding Council for England (HEFCE), or a Further Education College, which also provides education for 16–18 year-olds. For the purposes of this study, we are going to be talking specifically about universities, which cater to over 80 % of the student population (Universities UK 2014).

N.-A. Bradshaw (✉)
University of Greenwich, England, UK
e-mail: n.bradshaw@gre.ac.uk

© Springer Nature Singapore Pte Ltd. 2017

L.N. Wood and Y.A. Breyer (eds.), *Success in Higher Education*,
DOI 10.1007/978-981-10-2791-8_6

Universities receive funds administered by the Higher Education Funding Council England but are currently also able to charge students tuition fees of up to £9000 per year; students have access to government-funded loans to pay for their studies.

In 2014–2015 the number of students going into higher education was around 30 % of 18-year-olds. The student population is mainly made up of 18- to 24-year-olds with 11 % classified as mature students (over 24). Of those students classed as UK or EU nationals 23 % are non-white (Higher Education Statistics Agency 2015).

Before 1992, degrees could be studied at a university or a polytechnic. As a result of the *Further and Higher Education Act 1992,* most polytechnics became universities. They are now known as "post-1992" or "new" universities. These universities, of which Greenwich is one, tend to have a greater diversity in the student body in terms of family income, social class, and cultural origin.

Background

The University of Greenwich (founded in 1890 as Woolwich Polytechnic and later Thames Polytechnic) comprises four faculties across three campuses in south-east London and Kent, UK. The University has a mix of mature students and school leavers among its 20,000 student body, with 39 % over the age of 24. Over half the student body is classified as non-white. The Department of Mathematical Sciences is part of the Faculty of Architecture, Computing, and Humanities and is situated at the Old Royal Naval College in Greenwich. The Department currently has 432 undergraduate students but in 2010, when this project was started, it had approximately 250 undergraduate students.

Challenges and Motivation

In 2010 the Department of Mathematical Sciences, like all mathematics departments, was looking for ways to boost student success and improve retention. As a result of "Curriculum 2000" and subsequent changes to the content of A-level mathematics in England, the Department (like many others) was experiencing great variation in the mathematical skills and confidence of its intake (Vorderman 2011). Some students, despite good grades in school mathematics, were having difficulty in keeping up with the taught material. At the other end of the spectrum, the Department had a number of students with exceptional ability who needed stretching.

The author's motivation for the Maths Arcade stemmed from reading the proceedings of a conference, *Addressing the Quantitative Skills Gap: Establishing and Sustaining Cross-Curricular Mathematical Support in Higher Education*, on mathematical support and, in particular, the keynote address by Hoyles (2010). In this Hoyles acknowledged the varying backgrounds and confidence of students entering university to read quantitative subjects, but insisted that it is the university's responsibility to provide the necessary support. Also in these conference proceedings was a paper on the Maths Café at Portsmouth, which provided mathematics support for their students (Pevy 2010). At around the same time, the author was asked to review the new edition of the influential book *Thinking Mathematically* by John Mason and others (Mason et al. 2010) for the mathematics education journal *MSOR Connections* (Bradshaw 2010). In reading this book, the present author was struck by, amongst the mass of thought-provoking material, Mason's comments on the importance of working to develop and inspire our exceptionally able students. From these sources, the basic idea for the Maths Arcade was developed.

Definition of Retention and Success

The UK Higher Education Academy (Higher Education Academy 2015) described retention and success as follows:

> 'Retention' in the UK is about students remaining in one HE institution and completing their programme of study within a specific timeframe. 'Success' recognises that students benefit from HE study in a wide range of ways, including personal development and progression into the labour market or further learning.

Retention and success involve inclusion, ensuring the full and equitable participation in and progression through higher education (HE) for all students (HEA 2015). So one of the key questions for higher education institutes is: how they can best ensure that students complete their program of study? To answer this, it is important to look at the various factors which can cause students to drop out. Much research has focused on this in recent years. A summary of the research has been undertaken by Jones (2008), who cites Yorke and Longden's (2008) recent survey of students withdrawing from university, giving the following as contributory factors for non-completion:

- poor quality learning experience,
- not coping with academic demand,
- wrong choice of field of study,
- unhappy with location and environment,
- dissatisfied with institutional resourcing,
- problems with finance and employment, and
- problems with social integration.

Some of these issues, in particular, those around academic demand, problems with finance, and social integration were similar to those issues affecting students in the mathematics department at Greenwich. While acknowledging that some students drop out for good reasons, the Department hoped that more interventions could help avoid losing potentially successful mathematicians.

There are a large number of papers written on ways to aid the transition of students from school to higher education in different subject disciplines with Hodgen et al. (2014) and Grove et al. (2015) focusing solely on mathematics. Williams (2015) acknowledges that problems of transition to higher education mathematics courses used to be solely connected with the demands of "advanced mathematical thinking", whereas now the social and cultural aspects have led many higher education institutes (HEIs) to look at their teaching and learning practices. Again these ideas influenced the Department's thinking.

How to Measure Success?

For the purposes of this chapter we measure success in terms of the proportion of students passing modules or completing degrees, National Student Survey (NSS) scores on relevant questions, and student feedback on the graduate job application process. The NSS is a UK-wide survey completed each year by final year undergraduate students. The survey asks 23 questions to gather student opinion about their degree program. Despite the problematic nature of accepting student satisfaction as a measure of success (Braga et al. 2014), it remains an influential source of information that prospective students use to make their choice regarding which HEI to attend (NSS 2015).

Retention and Success

Department Strategy

The Department of Mathematical Sciences at Greenwich aims to recruit about 100 new undergraduate students each year. The various mathematics degree programs have a large applied content, with a strong emphasis on statistics and operational research. Representative employers and alumni have been consulted over new course content in recent years to ensure that the curriculum is preparing graduates for relevant employment.

As described above, the Department faces many challenges concerning its diverse student body, and as a result, staff have employed various innovations in their practice to tackle retention and student success. In 2008 the author instigated a peer-mentoring scheme (Bradshaw et al. 2011) which has continued ever since, run by different staff but following essentially the same format. Second-year students are trained to mentor groups of first-year students. Mentors are selected and trained during the summer between their first and second year and are then placed with a group of about six new first year students. If there are enough mentors then sometimes two are assigned to each group. Mentors are chosen carefully and given appropriate training and guidelines as to how and when to contact new students. They play an active role during the new students' first week, in terms of helping them to settle into university life. This scheme has been found to be very successful, with several past students saying that they would not have coped so well had it not been for their mentor, and even that they would have dropped out at the beginning of their course but for the support of their mentor.

The author was also involved in the rejuvenation of the University Maths Society (MathSoc), both as a mature student and then again as a new lecturer. The Society encourages student involvement; organises academic and social events for new and current students; and produces a regular mathematics newsletter, *Prime Times*. Over the years, MathSoc has helped to enhance the community feel within the Department.

The introduction of the Maths Arcade was the result of further thinking about transition and what could be done with limited resources in terms of staff numbers and time. The intention was to simultaneously stretch the more able students, support those who were struggling, and also provide an opportunity for students to get to know each other and thus aid the transition between school and university and again between first and second year.

The Development of the Maths Arcade

Staff in the Greenwich Department felt that a key strategy to improve retention and success was to maintain a sense of community among its students, to encourage them to feel that they were part of a professional mathematical community. If new students were to develop friendships with undergraduates who were part way through their studies, they could be motivated by the success of students in previous cohorts, both academically and in career terms. The Department was particularly keen to help mathematics students overcome the shyness and social inhibitions characteristic of some of those drawn to the subject, and to develop stronger friendships, as well as to increase their attachment to the University and to their chosen discipline. Activities such as the encouragement of an effective student Mathematics Society (MathSoc) and the introduction of a mentoring scheme for new students had been successfully introduced with these objectives in mind.

To build on these activities, the Department wished to promote collaborative learning among students [motivated in part by Swan (2006) and by the work of Uri Treisman (Steele 2011)]. It also wished to tackle the problems noted earlier of students from diverse backgrounds, with some students struggling and others needing greater challenges. The Maths Arcade was created to address these issues, to provide access to help and support from academics, and opportunities for investigating more demanding mathematics, in an informal social situation.

Influenced by classic works such as Polya (1945) and more recent research by Burkhardt and Bell (2007) and Badger et al. (2012), the Department wished to encourage extracurricular mathematical problem solving among its students to help the development of mathematical modes of thinking. Giving students time to experience a different sort of problem solving was at the heart of the initial Maths Arcade.

It was decided that the Maths Arcade should consist of a one-hour-a-week drop-in session offering a number of activities. Students and tutors might simply come to eat their lunch together, share, for example, mathematical gossip about the latest development in the attempt to prove the Goldbach Conjecture, discuss recent popular mathematics books, or show off a new mathematical magic trick. Students would be encouraged to bring any work they were struggling with so this could be discussed in an informal atmosphere. Puzzles and strategy games would be available, and these quickly became a major part of the attraction of the Arcade for students, with the opportunity to challenge and beat their tutors at simple games becoming a particular draw.

Getting Started

In the inaugural year the Maths Arcade was chiefly promoted to new first-year students, although students from other years, including postgraduates, were welcome. Importantly, staff were also encouraged to attend by advertising this session as one of their "office-hour" slots where they were available to see students. Staff attendance is particularly important for this activity and students often comment on the value for them of the opportunity for informal interactions with their tutors. Trowler and Trowler (2010) state that "interacting with staff has been shown to have a powerful impact on learning especially when it takes place outside of the classroom." It is this interaction that the Maths Arcade is keen to promote. This staff-student interaction is commented on positively by Croft and Grove in their discussion concerning progression within mathematics degree programs (Croft and Grove 2015).

In the first week of term, the second year student mentors were encouraged to bring their mentees to the Maths Arcade. This created strong interest among the new first years, and many of them stayed engaged and continued to attend, albeit for a variety of reasons.

Feedback from students indicated that some were attracted primarily by the games, whereas others came for the social interaction or to obtain help with the academic material. Some tried different games each week, while others played the same one, again and again, examining the different possibilities and strategies. For example, what difference does it make who starts; is it better to play defensively or to attack; when should one play safe, and when is it desirable to take risks? Unlike chess clubs which tend to be competitive, the activity was primarily social. Students were keen to discuss strategies and tactics, which develops their mathematical thinking in an unthreatening context. Indeed, at Maths Arcades in other universities, this strategic gameplay has often been the main focus of the activity and has encouraged students to pursue topics in the study of strategy games and, in some cases, theoretical game theory for final year dissertations (Rowlett 2015).

What was particularly pleasing to the Department's staff was the diversity of the students who attended, which showed that the initiative was reaching students who might be at risk of poor performance or losing motivation. Before this, other events put on by the Department had tended to attract students from a certain sort of background. This one, however, attracted students of different ages, abilities, social groups, and mathematical background. It was a very successful way of encouraging the students to get to know each other across a whole year group and boosted the group spirit and morale of the cohort.

Social Interaction

It can be extremely hard for mathematics students, who are often shy, to start conversations and make friends but a game (or any similarly focused activity) provides a natural talking point and facilitates conversation between reserved students. Staff would begin playing games with a small group of students and then move on to another group, leaving the students to continue playing and get to know each other better. This strategy appeared to work, and during the year lasting friendship groups emerged around the games.

The students also liked the fact that lecturers joined in and, more importantly, that they could beat them at various games. This encouraged students to gain confidence, realising that they had the potential to become members of the wider mathematical community. One of the most memorable sessions was when a member of staff played the board game Quoridor with three students. The game involves balancing racing one's own piece with the need to spend time blocking opponents' pieces. Rather than everyone trying to outwit the other three opponents, it became obvious that the students were working in collaboration so that the lecturer would not win. It was great fun, and the students did not seem to realise that the lecturer did not come out too badly as it took three of them to beat her!

Events like this worked to enhance the cohesion of the cohort and to create an environment in which students felt tutors were "on their side" in helping them learn.

The Games

Because of the desire to increase interaction between students and to get them talking about the games and the strategies involved rather than just enjoying playing competitively, it was important to choose appropriate games. There are a number of suitable commercial board games on the market. One of the students' consistent favourites so far is Quarto! (BoardGame Geek 2015) (a game devised by the Swiss mathematician Blaise Müller), which is described by Rowlett (2015). It contains playing pieces with four different attributes:

- Size—tall or short;
- Colour—light or dark;
- Fill—hollow or solid; and
- Shape—round or square.

The aim is to be the player to complete a row of four containing the same attribute; for example, four tall pieces regardless of colour, fill or shape, or four round pieces regardless of size, colour or fill. What adds to the interest of the game is that you do not choose which piece to play, but your opponent chooses your piece for you. So a winning strategy might be to try to engineer a situation where your opponent is only left with pieces that give you a win. This is easier said than done as it is hard to keep track of all the different possibilities that might produce a win. No two games are the same, and there are numerous ways that the students can investigate winning strategies.

A list of suggested games both for starting a Maths Arcade and also for a more established one can be found on the website of the Institute of Mathematics and its Applications (IMA) (Bradshaw 2015).

The choice of games is important. Those which have worked best at Greenwich have the following properties:

- simple, easy to understand rules;
- new to most people, so that there are no "experts" and new players do not feel disadvantage;
- quick to play—over in a few minutes, allowing several games in one session;
- offering potential for mathematical analysis of strategies and tactics; and
- sufficiently challenging so that there is no humiliation when a player makes a blunder and loses.

Quarto works well in this regard: games last about five minutes, and even experienced players often overlook winning moves, so that the games are good-humoured rather than intensely competitive. It offers opportunities for analysis—"what moves are safe in this position?", or "what will my opponent do if I give them this piece to play?". Players make strategic as well as tactical decisions. For example, a player who is confident in their ability to navigate tactical complexity might play to create positions with many unresolved threats of three like pieces in a line, forcing both players to be extremely careful, while a less experienced or confident player might play to block off such threats as soon as they arise. Some students at Nottingham Trent University have investigated other versions of the game (Rowlett 2014b).

Games like Quarto also offers students who are programmers the possibility of programming a computer to play the game, and thus to investigate different strategies. This is discussed further by Rowlett (2015). Such activities could be an excellent basis for a final-year project or group work, as has been successfully implemented at Salford (Bradshaw and Rowlett 2012).

Many of the games can be played with three or more players. In terms of mathematical strategy, that can be less satisfactory than the two-player version since one's chances of winning depend too much on the interactions between the other players, but multi-player games are socially rewarding and, for students studying decision mathematics, provide examples of multi-agent interaction.

The Greenwich experience is that games which are traditionally thought of as mathematical, such as chess, are less satisfactory in the Maths Arcade situation due to the emphasis on building relationships. Chess takes longer to play, has complex rules so that beginners cannot immediately play at a reasonable level, and is satisfactory only when the two players are well matched. A game which takes a significant time to play can have a greater negative impact on the loser whereas losing a five-minute game seems less significant because one can immediately try again! It is worth pointing out that more complex games like chess and Go can be used to build problem-solving stamina. However, the focus on friendship and relationship building at the Maths Arcade has meant that these longer games are actively discouraged.

Hex is the classic, short, strategy game independently invented by Piet Hein and John Nash and popularised by Martin Gardner (1959), in which two players take turns to play counters of their colour on a hexagonal grid, attempting to join two opposite edges with a continuous chain of their counters. Explicit winning strategies have been found for a 9×9 board but not larger boards. In the basic game, there is a definite advantage for the first player which is mitigated by a small change to the rules. Nash showed that Hex can never end in a draw as it is not possible to fill the board without there being a continuous chain from one side of the board to the other in one of the players' colours; a nice demonstration of mathematical analysis in a game. Indeed, there is a non-constructive proof that the first player has a winning strategy.

Other similar, short, strategy games include Pylos, Solomon's Stones, and Pentago. A little about their suitability has been written about by the author in an article for *Mathematics Today* (Bradshaw 2014).

Puzzle of the Week

To stretch the more able students a weekly puzzle or puzzles were introduced (Bradshaw and Rowlett 2012). These are similar in style to (and often adapted from) those recreational mathematics puzzles found in books by Martin Gardner, Raymond Smullyan, and other authors. Answers could be submitted each week, with prizes for the most correct answers over a term, and a scoring system was devised which was intended to maintain interest over several weeks. As the Arcade has grown and matured, some students come just to get this question of the week and spend their time in the Arcade working on it (despite the fact that the students can access it via the University virtual learning environment).

There is evidence from conversations, emails, and other student feedback that some students enjoyed and actively took part in this activity. However, it tended to be the case that after the first few weeks very few students submitted their solutions for the term competition, and indeed the competition provoked some unwanted behaviour: some, initially successful students were dropping out of the competition if they were not winning! As a result, the competitive aspect of the weekly puzzles has been suspended for the time being. More work needs to be done to investigate this, but current thinking is that many students are happy just to do the activity without competing and that the competitive element has not been successful.

Maths Support

Some of the students who attend the Maths Arcade regularly come purely to work on the week's tutorial questions and to ask for help when necessary. They do not always want to join in with the games but are grateful that staff are on hand to help and explain things when they are stuck, and they enjoy working in a social environment.

It was obvious from the start that some mathematics students came to the Maths Arcade who would not have wished to identify themselves as needing help by going to a tutor's office. However, they were happy to turn up at the Arcade, start work, and then casually ask questions without it looking as if they were having difficulty. Other students would migrate to the help sessions after having played some of the games, or would come to listen when they realised a useful mathematical topic was being discussed.

Previously in 2007 a drop-in mathematics support session had been instigated for mathematics students, but this had folded due to lack of uptake. Students felt that by attending, they would be indicating to their friends and tutors (and perhaps to themselves) that they were not coping with the course material. Drop-in maths support for students of other disciplines works well at Greenwich and elsewhere (Lawson 2015), but our experience is that it did not work for our maths undergraduates when this was the sole focus.

Outside Speakers and Other Events

During the first year of the Arcade outside speakers were brought in on a couple of occasions. For example, one of these sessions was on the mathematics associated with origami. While such events attracted a good audience, the sessions did not seem to be what the students wanted as they did not allow students as much time for interaction either between themselves or with staff. Our preference now is that such events are organised apart from the Maths Arcade.

On a couple of occasions games competitions have taken place at the end of term with one very tense and memorable final played on Quarto. Other similar competitions such as Countdown and memorising digits of pi have also taken place. The main benefit of these sorts of events seems to be that students really like the fact that staff compete alongside them, and it is just as possible for students to win as staff.

Initial Student Feedback

In the first year of running the Arcade the first year, students were asked, as part of their personal development planning, to write about a mathematics event in which they had participated. About two-thirds of the cohort chose to write about the Maths Arcade. The only negative comments received were that 1 h was not enough and that the timing might be better for some if it occurred after lectures had finished for the day. These were both acted on for the next year, although the Arcade has now reverted to 1 h a week due to problems with room availability. Positive comments included:

> I like to go to the Maths Arcade because all of my tutors attend it.

> The people who were once strangers to me when I first started [attending the Maths Arcade] are now some of my closest friends.

> I felt somewhat dubious about the word "enjoyable" being used but I'm glad to say I was quickly proved wrong.

> [It is] a really good way to meet people and get to know the lecturers in a more informal environment.

> Attending Maths Arcade has been a major help for me this year and a huge factor in me having such successful and enjoyable studies.

Initially, we had focused on the benefits to students and had not thought of the benefits to tutors. However, the staff attending have found these sessions particularly valuable, as they have enabled us to get to know the students in an informal setting and such interaction has helped to sort out student problems early before they have escalated.

Graduate Feedback

Many graduates have commented on how the Maths Arcade has helped them in the graduate job application process. They report that the communication skills and tactical and strategic problem-solving skills that they developed through this extracurricular activity have helped persuade prospective employers of their potential.

Table 6.1 Increase in student numbers and pass rate between 2009–2010 and the year following the introduction of the Maths Arcade

	2009–2010	2010–2011
Cohort total	87 students	164 students
First-year pass rate	91 %	96.4 %

Impact

The first year the Maths Arcade ran, 2010 to 2011, it was found that student attainment across all four first-year courses had improved on the previous year. The intake in 2010 was larger than in previous years due to changes to the admissions process, which meant that first year teaching staff and personal tutors were particularly stretched; and yet retention improved (Table 6.1).

Also, since starting the Maths Arcade, the response from students in the NSS regarding whether their degree has improved their communication skills has increased from 61 to 96 %; and the percentage of students who thought they were good at tackling unfamiliar problems has increased from 75 to 91 %.

It is hard to gain statistical evidence of the value of the Maths Arcade in helping graduates into their careers. Data from the government's Destination of Leavers of Higher Education (DLHE) survey are inconclusive and the survey's classification of graduate jobs is flawed but, anecdotally, students report that their confidence in problem solving and communication has been a major factor in their being successful in applying for graduate jobs.

Dissemination and Adoption Elsewhere

Following the initial pilot in 2010, the Maths Arcade at Greenwich has continued to run in the mathematics department each year. After internal dissemination there has been interest in the Maths Arcade from the engineering faculty and some staff in the business faculty have used the Arcade games with their students to increase their strategic-thinking skills.

Those involved in establishing the Maths Arcade at Greenwich have talked about it at conferences and in invited presentations at workshops on transition and retention. A condition of the HE STEM funding was that the Department present its experience at subject conferences which raised interest in the mathematics education community, as a result of which Maths Arcades have been established in other institutions. Some of these were set up with funding from the National HE STEM Programme Mathematics Curriculum Innovation Fund, others from an IMA grant and others from institutional or departmental funding. There are similarities between these Arcades, but they are not all the same.

As a result of a presentation at Maths Jam (a recreational mathematics conference held annually in the UK) (Rowlett 2014a) and events run by the IMA

(Bradshaw 2014), some schools have become interested and invested in some of the games, as they are often the sort that can be played by a wide variety of ages and abilities (the games often say “age 9–99”). Some of the final year students at Greenwich have actively taken games into schools and started clubs/Arcades. These have tended to be students in the Undergraduate Ambassador Scheme (UAS 2013) who gain school experience as part of their mathematical degree.

Differences

Some of the earlier Arcades have been described by Bradshaw and Rowlett (2012). An example of a successful implementation is the Arcade at Sheffield Hallam University. This is increasing in popularity because, having recently moved into a new building, the mathematics department at Sheffield Hallam now has its own space (Cornock 2015). They have a communal staff/student area which is ideal for Maths Arcade-style activities (Waldock 2015). This space has contributed to the Department’s student-staff cohesion but, sadly, many departments, like Greenwich, do not have access to suitable space of this type.

Some Maths Arcades have used the games to inspire student project work. In the case of Salford (Bradshaw and Rowlett 2012) this was something that whole cohorts were involved in, whereas at other HEIs this has more often been on an individual basis.

Some Arcades, such as the one at Bath, have been positioned outside the mathematics department in the Maths Support Centre and so have attracted student involvement from other disciplines such as engineering. This has provided students with the opportunity for cross-discipline discussion but has limited the involvement of subject-specific staff.

The competition element has been used in Arcades such as Leicester, which has students competing in a house system. Sheffield Hallam has used Maths Arcade sessions to host high-speed Rubik-cube solving events, and a lecturer in that department has now developed a course which teaches group theory through Rubik cubes (Cornock 2014).

The Arcade in Manchester has used strategic games available on iPads as well as board games, and they are particularly keen to get input about this from Ph.D. students (Bradshaw and Rowlett 2012).

Further Research

In 2014 representatives from several Maths Arcades met in Sheffield to discuss evaluating this work. Under the oversight of Peter Rowlett (then at Nottingham Trent University), a student from Nottingham Trent undertook a study to look at the success of the Maths Arcade and to see if any lessons could be learned from the different approaches, as well as to create simple instruction cards for the games (Webster and Bradshaw 2014). Five Arcades took part in this task (Greenwich, Nottingham Trent, Reading, Salford, and Sheffield Hallam), distributing a questionnaire to mathematics students who had and had not attended the Maths Arcade at these institutions.

The results indicated that the Maths Arcade aided the transition from school to university by helping students to be more relaxed around the staff, encouraging students to ask for help on other aspects of their course, and enabling them to enhance their mathematical thinking skills. These are all cited by Croft and Grove (2015) as being factors affecting transition and progression.

There were 295 responses to the survey with 124 (42 %) who had attended the Maths Arcade at least once. Full results can be found in Rowlett et al. (2014). Of those who had attended, 47 % said that they had made friends at the Maths Arcade, and 95 % said that they were happy with staff being present, although some said that they would like more interaction with staff. Of the free-text comments on the "best" things about the Maths Arcade, 31 out of 90 mentioned the games themselves, whereas 19 highlighted the social environment.

When asked what would encourage more frequent attendance of the Maths Arcade at Greenwich, the two most popular answers were: food and better timetabling. The former is a perennial optimistic student request but, for cost reasons, food and drink cannot realistically be provided; though the Department provides chocolate biscuits at the Arcade, and these are popular with students.

The Nottingham Trent research, and the feedback from our students has made the point that one of the most important factors of the success of a Maths Arcade is the timetabling. If this is at a convenient time and in a convenient location (with regard to the students' timetables) then students will attend. Ideally, the timetable can be managed so that all cohorts have classes immediately before or after the Arcade, and a midday timing will encourage students to bring their lunch to the Arcade. However, if the Arcade is on a day when students have no classes or have to wait for a long time before or after a class, then student attendance will be reduced. Unfortunately, the complexity of University-wide timetabling at Greenwich and the intense demands on the available space makes compromise necessary regarding the timetable.

The ideal situation would be where the Department can offer its dedicated space for the Maths Arcade. As noted above, Sheffield Hallam's department has just arrived at this fortunate position, and it will be interesting to see how their Arcade continues to evolve.

Conclusion

This chapter has discussed the motivation for the Maths Arcade and how it has been implemented in different institutions in the UK. It argues that it has been used both to support and to retain mathematics students, and discusses how it has contributed to student success both academically and, anecdotally, in terms of progress into graduate careers. Some of the lessons from the recent research (Rowlett et al. 2014) mentioned in the last section might be useful for mathematics departments in other HEIs, or indeed, other disciplines, thinking of implementing something similar.

References

Badger, M., Sangwin, C., Ventura-Medina, E., & Thomas, C. (2012). *A guide to puzzle-based learning*. Birmingham, UK: National HE STEM Programme.

BoardGameGeek. (2015). *Quarto!* http://boardgamegeek.com/boardgame/681/quarto

Bradshaw, N. (2010). *Book review: Thinking mathematically. MSOR Connections, 10*(3), 49–50.

Bradshaw, N. (2014). The maths arcade. *Mathematics Today, 50*(5), 265.

Bradshaw, N. (2015). *The Maths Arcade*. http://www.ima.org.uk/i_love_maths/games_and_puzzles/the_maths_arcade.cfm.html

Bradshaw, N., Greer, S., & Moreno, E. (2011). *A case study in peer-mentoring, graduate mentoring and employer mentoring: Helping to develop the effective student journey.* https://showtime.gre.ac.uk/index.php/edu/shift2011/paper/viewPaper/58

Bradshaw, N., & Rowlett, P. (Eds.). (2012). *Maths Arcade: Stretching and supporting mathematical thinking*. http://www.mathcentre.ac.uk/resources/uploaded/mathsarcade.pdf

Braga, M., Paccagnella, M., & Pellizzari, M. (2014). Evaluating students' evaluations of professors. *Economics of Education Review, 41*, 71–88.

Burkhardt, H., & Bell, A. (2007). Problem solving in the United Kingdom. *ZDM, 39*, 395–403.

Cornock, C. (2014). *Using a Rubik's cubes to teach group theory.* Kings College London.

Cornock, C. (2015). Maths Arcade at Sheffield Hallam University: Developments made in a new space. *MSOR Connections, 14*(1), 54–61.

Croft, T., & Grove, M. (2015). Progression within mathematics degree programmes. In M. Grove, T. Croft, J. Kyle, & D. Lawson (Eds.), *Transitions in undergraduate mathematics education* (pp. 173–189). Birmingham, UK: University of Birmingham.

Gardner, M. (1959). *The scientific American book of mathematical puzzles and diversions*. New York, NY: Simon and Schuster.

Grove, M., Croft, T., Kyle, J., & Lawson, D. (Eds.). (2015). *Transitions in undergraduate mathematics education* (pp. 173–189). Birmingham, UK: University of Birmingham.

Higher Education Academy. (2015). *Retention and success*. https://www.heacademy.ac.uk/workstreams-research/themes/retention-and-success

Higher Education Statistics Agency. (2015). Retrieved from Higher Education Statistics Agency: Higher Education Statistics Agency. https://www.heacademy.ac.uk/workstreams-research/themes/retention-and-success

Hodgen, J., McAlinden, M., & Tomei, A. (2014). *Mathematical transitions*. York: Higher Education Academy.

Hoyles, C. (2010). Mathematics and the transition from school to university. In C. M. Marr & M. J. Grove (Eds.), Responding to the mathematics problem: The implementation of institutional support mechanisms (pp. 4–5). St Andrews University: MSOR. http://www.mathcentre.ac.uk/resources/uploaded/mathssupportvolumefinal.pdf

Jones, R. (2008). *Student retention and success: A synthesis of research.* https://www.heacademy.ac.uk/sites/default/files/wp_retention_synthesis_for_pdf_updated_090310_0.pdf

Lawson, D. (2015). Mathematics support at the transition to university. In M. Grove, T. Croft, J. Kyle, & D. Lawson (Eds.), *Transitions in undergraduate mathematics education* (pp. 39–56). Birmingham, UK: University of Birmingham.

Mason, J., Burton, L., & Stacey, K. (2010). *Thinking mathematically*. Harlow: Pearson Education.

NSS. (2015). *About the National Student Survey*. http://www.thestudentsurvey.com/about.php

Pevy, L. (2010). The Portsmouth University Maths Café: Making a virtue of necessity. In C. M. Marr & M. J. Grove (Eds.), *Responding to the mathematics problem: The implementation of institutional support mechanisms* (pp. 17–22). MSOR: University of St Andrews.

Polya, G. (1945). *How to solve it: A new aspect of mathematical method*. New Jersey, NJ: Princeton Science Library.

Rowlett, P. (2014a). *Games used at the Maths Arcade*. http://www.mathsjam.com/conference/talks/2014/PeterRowlett-maths-arcade-games.pdf

Rowlett, P. (2014b). *Quarto games of different sizes*. Nottingham Trent University.

Rowlett, P. (2015). Developing strategic and mathematical thinking via game play: Programming to investigate a risky strategy for Quarto. *The Mathematics Enthusiast, 12*(1–3), 55–61.

Rowlett, P., Webster, K., Bradshaw, N., & Hind, J. (2014). National evaluation of the Maths Arcade. *CETL-MSOR 2014*. Cardiff: sigma.

Steele, C. M. (2011). *Whistling Vivaldi: How stereotypes affect us and what we can do*. New York, NY; London: W. W. Norton and Company.

Swan, M. (2006). *Collaborative learning in mathematics: A challenge to our beliefs and practices*. Leicester: NIACE.

Trowler, P., & Trowler, V. (2010). *Student engagement evidence summary*. http://eprints.lancs.ac.uk/61680/1/Deliverable_2._Evidence_Summary._Nov_2010.pdf

UAS. (2013). *The undergraduate ambassador scheme*. http://www.uas.ac.uk

Universities UK (2014). *Patterns and trends in UK higher education*. London: Universities UK.

Vorderman, C. (2011). *A world-class mathematics education*. Conservative Party. http://www.tsm-resources.com/pdf/VordermanMathsReport.pdf

Waldock, J. (2015). Designing and using informal learning spaces to enhance student engagement with mathematical sciences. *MSOR Connections, 14*(1), 18–27.

Webster, K., & Bradshaw, N. (2014). *Selected rule sheets*. http://www.ima.org.uk/viewItem.cfm-cit_id=384686.html

Williams, J. (2015). Mathematics education and the transition into higher education. In M. Grove, T. Croft, J. Kyle, & D. Lawson (Eds.), *Transitions in undergraduate mathematics education* (pp. 25–37). Birmingham, UK: The University of Birmingham.

Yorke, M., & Longden, B. (2008). *The first-year experience of higher education*. York, UK: Higher Education Academy. http://www.heacademy.ac.uk/ourwork/research/surveys/fye

A2. Booklet on Maths Arcades edited with Peter Rowlett

Bradshaw, N. and Rowlett, P., eds., 2012. *Maths Arcade: stretching and supporting mathematical thinking*. Birmingham: National HESTEM. Available at: http://www.mathcentre.ac.uk/resources/uploaded/mathsarcade.pdf [Accessed 12 March 2016]

A3. Paper by colleague from Sheffield Hallam

Cornock, C., 2015. Maths Arcade at Sheffield Hallam University: Developments made in a new space. *MSOR Connections*, 14(1), 54-61. Available at: https://journals.gre.ac.uk/index.php/msor/article/view/253 [Accessed 12 March 2016].

A4. Research paper with four participating universities.

Rowlett, P., Webster, K., Bradshaw, N. and Hind, J., 2019. Evaluation of the Maths Arcade initiative at five U.K. universities. In: *The Mathematics Enthusiast.* 16(1&2), Article 23.

Evaluation of the Maths Arcade initiative at five U.K. universities

Peter Rowlett, Sheffield Hallam University[1]
Kingsley Webster, Nottingham Trent University
Noel-Ann Bradshaw, University of Greenwich
James Hind, Nottingham Trent University

Abstract
The Maths Arcade is a regular, optional drop-in session to play strategy games and puzzles, taking place at a range of U.K. universities. The main aims are to support students, create a maths-themed staff-student community and develop mathematical thinking through strategy game-play. At some universities, the Maths Arcade has additional aims, including motivating curricular work, linking to peer assisted learning and promoting cross-disciplinary interaction.

The games used are strategy games with simple rules which have no explicit link to mathematics but appeal to logical thinking. The games and activities typically used at a Maths Arcade are described and an example of a deep investigation is given as a case study.

An evaluation of the Maths Arcade at five U.K. universities was completed by distributing a questionnaire to attenders and non-attenders. Students who attend more sessions were more likely to report making friends at the Arcade, and a majority of students said that staff presence is helpful and they would like staff to attend more often, results which support the aim of creating a mathematical community. Students report liking the games, and those who attend more often are more likely to prefer games that are more open to analysis, supporting the aim to develop mathematical thinking through analysis of gameplay. Negative feedback focused mostly on practicalities, including quality of advertising and scheduling of Maths Arcade sessions.

1. Introduction
The Maths Arcade is a regular drop-in session to play strategy games and puzzles, offering an informal support mechanism, the chance to develop a staff-student mathematics-themed community and the opportunity to develop mathematical thinking. This article describes the Maths Arcade and its implementation at several UK universities, and details the results of an evaluation via survey of students at five universities running Maths Arcades.

2. About the Maths Arcade
The Maths Arcade aims to support struggling learners and stretch more confident learners by developing mathematical thinking and problem-solving skills through playing strategy games and tackling puzzles, while providing an opportunity for staff and students to interact together in a social, mathematics-themed extra-curricular environment. Typically, a weekly drop in session is offered where a variety of strategy games and puzzles are available for students to play with each other and members of staff. These might be simply played, to develop a mathematical-themed social environment as an informal support mechanism for students, or strategies might be analysed, to develop students' mathematical thinking and stretch more confident learners. It can also be used to provide a focal point for maths students from different year groups getting together with members of staff and postgraduate students to learn from each other. Trowler and Trowler (2010) state that "interacting with staff has been shown to have a powerful impact on learning especially when it

[1] p.rowlett@shu.ac.uk

takes place outside of the classroom". It is this interaction that the Maths Arcade is keen to promote, and "encouraging more opportunities for staff/student interactions" is highlighted by Croft and Grove (2015) as an advantage of the Maths Arcade initiative in relation to enhancing student experience (p. 181).

The Maths Arcade was initiated by Bradshaw (2011) at the University of Greenwich in 2010, and was expanded to eight universities in 2012 as part of the National HE STEM Programme (Bradshaw and Rowlett, 2012). Further universities have received funding since then, via internal funds or funding from the Institute of Mathematics and its Applications (IMA); for example, a Maths Arcade was set up at Nottingham Trent University in 2013 as a staff/student collaborative partnership using IMA funding (Webster and Rowlett, 2013).

The initial Maths Arcade was designed to support students particularly at the transition between school or college and university. Whilst many students from other disciplines are keen to attend the sort of maths support sessions described by Lawson (2015) at Greenwich and elsewhere, at that time Greenwich mathematics students were observed to be reluctant to attend 'help sessions'. This was apparently due to a perception that these are for weaker students and a reluctance to identify themselves as such. The Maths Arcade was designed to provide a venue for mathematical talk, games and problem-solving, where students could get help from academic staff or peers. Sessions attracted both stronger and weaker students. Some attended to play games, while others attended to work through exercises and talk to staff. At some universities, the Maths Arcade is used for formal input into the curriculum. Badger et al. (2012) promote "puzzle-based learning" and report a positive influence on problem-solving ability, independent learning skills and motivation (p. 1), as well as creativity and modelling skills, particularly in group learning activities (p. 8). These skills are key to mathematics degree programmes (QAA, 2015).

Carpenter (2011), giving a student view, wrote about how attending the Greenwich Maths Arcade was "of enormous benefit to [him] both on an academic and social front" and how all maths students also benefited from "fun, enjoyment, queries, banter and a light hearted approach to all aspects of mathematics" (p. 30). Informal evaluation at Greenwich has been extremely positive (Bradshaw, 2011).

As new Maths Arcades were set up, each started with a slightly different implementation adapted to suit local circumstances; some case studies are given by Bradshaw and Rowlett (2012). For example, the activity at the University of Salford included a formal project in game theory (Chadwick, 2012), that at Sheffield Hallam University included a link to the peer assisted learning scheme (Cornock and Baxter, 2012) and that at the University of Bath had a focus on cross-discipline interaction and support (Cliffe et al., 2012).

2.1 Games used

The games are chosen as unintimidating activities which, to the uninitiated, do not obviously seem connected with maths. Most are relatively new (and commercially available) strategy games which have simple rules and can be played quickly, but which are likely to appeal to mathematicians. Well-known games of the right sort, such as Chess or Go, are best avoided in case prior knowledge by some students causes an imbalance of ability, or the appearance of such an imbalance. Also, a game of Chess can take a whole Maths Arcade session, while shorter games have a focus on repeated play to develop a strategy. Chess tends to be available, however, as some students are very keen to play it. Choice of games at different Arcades varies due to differing funding levels and local interest, but some of the most frequently purchased games include Hex, Solomon's Stones, Quixo, Quoridor, Quarto, Pentago and Pylos.

Hex is the classic game independently invented by Piet Hein and John Nash and popularised by Gardner (1959), in which two players take turns to play counters of their colour on a hexagonal grid, attempting to join two opposite edges with a continuous chain of their counters. Solomon's Stones is a two-player game similar to Nim's game, which was also popularised by Gardner (1959) and analysed by Conway (1976) in *On Numbers and Games*. Solomon's Stones uses a triangular arrangement of 28 stones. Players take it in turn to remove stones in the same row or column and try to avoid being the person who takes the last stone. Pylos involves building a pyramid of spheres, requiring three-dimensional thinking. Quoridor involves moving your piece across a chessboard while placing walls to obstruct your opponent. This is a game that those interested in programming particularly seem to enjoy. Pentago has similarities with noughts and crosses on a 6×6 board, but after each move, a quarter section of the board must be rotated, which can significantly change the position. Quixo, another noughts and crosses variant, involves sliding rows of blocks across a 5×5 board to form five in a row. Quarto, a game devised by Swiss mathematician Blaise Müller (Gough, 2015; p. 26), is described below.

2.2 Activities at the Maths Arcade

As an extra-curricular activity, the Maths Arcade does not involve formal attendance or pre-determined structure. Rather, it is a drop-in session where students choose activities in which to participate. New visitors generally enjoy learning to play unfamiliar games. However, as time passes attendees tend to start to think about strategy. Questions occur, such as what is the best strategy to maximise your chance of winning? Is there an advantage to making the first move? Is there a position on the board that is advantageous to capture? These questions can, prompted by staff or unprompted, lead to deep conversations and investigations. Some students discuss what would happen if the rules of a game were changed. Some use computers to investigate possible strategies. This is precisely the sort of investigation, building up mathematical skills, that the Maths Arcade aims to encourage. At its most advanced, the Maths Arcade has been used to motivate project work in game theory.

The following case study is designed to show some of the mathematical complexity which can be examined using a fairly simple game as a starting point.

Case study: Playing quarto on different sized boards

A Quarto board has sixteen spaces arranged in a 4×4 grid. Each game piece has four attributes taking one of two values, namely it is: tall or short; black or white; round or square; and, flat-topped or dimpled. Since each combination of attributes is used, this system uses $2^4 = 16$ pieces. Note that the number of pieces matches the number of spaces on the board.

Players take turns to choose an unplayed piece and hand it to their opponent, who places it in any unused space on the board. The player who places the fourth in a row, column or diagonal which all match any one attribute wins (i.e. four that are square, or four that are dimpled, etc.).

One of the authors and a student, speaking about how to extend noughts and crosses into Quarto, realised that we cannot play on an arbitrary-sized square board while maintaining the rule that the number of pieces equals the number of spaces on the board. Specifically, the counterexample discovered is that with three attributes and a 3×3 board, the size used for standard noughts and crosses, we cannot play; observe that $2^3 = 8 \neq 9 = 3^2$.

In general, then, for m attributes we have 2^m pieces and require this to be equal to the number of spaces on an n×n board. That is, $2^m = n^2$. Then we require $m = 2\log_2 n$. For a viable game (i.e.

integer m), we have that m is even and n is a power of 2. For example, six attributes uses 64 pieces on an 8×8 board, while fourteen attributes uses 16,384 pieces on a 128×128 board.

In fact, we can generalise so that pieces may take any number of attributes and boards can be made in higher dimensions. Then, a d dimensional board of side length n using pieces which have m attributes taking each of k values requires $k^m = n^d$, that is, $m = d \log_k n$. For example, four binary attributes on a 2×2×2×2 4-cube would use $2^4 = 2^4 = 16$ pieces, while 15 ternary attributes on an 27×27×27×27×27 5-cube would use $3^{15} = 27^5 = 14{,}348{,}907$ pieces. Setting $n = k^p$ to give $m = dp$ allows viable game configurations to be generated for positive integer p.

At Nottingham Trent University, students and staff have attempted to play Quarto on an 8×8 board and in 4 dimensions on a 2×2×2×2 board. The latter option can be played with the usual 16 Quarto pieces using a modification of a set of rules for 4-dimensional noughts and crosses (Butler, 2012). The 8×8 option requires a way to represent pieces with six attributes rather than the usual four. To do this, label each attribute either 0 or 1: white (0), black (1); short (0), tall (1); round (0), square (1); dimpled (0), flat-topped (1). Using a positional system in this order, the attributes for each piece in the game as sold are represented by a four-digit binary number. For example, 0100 would be white, tall, round and dimpled; 1001 would be black, short, round and flat-topped. The winning condition is met if four pieces in a line share one digit in common. For example, 0100 and 1001 are both round, and so both have third digit 0. Label each piece q_c where c is the decimal number representing the attributes. For standard Quarto, then, use $0 \leq c < 16$. Now, other board sizes can be assigned pieces using different length binary numbers. For example, six attributes uses $0 \leq c < 64$, while fourteen attributes uses $0 \leq c < 16384$. In practice, due to its complexity, 8×8 Quarto was played in correspondence mode via Twitter, with players taking turns to indicate the coordinates of a position on the board and the decimal number corresponding to the next piece to hand over. This method of labelling pieces enables their encoding in a computer program; an idea explored by Rowlett (2015).

3. Evaluation method

The evaluation was planned by participating universities at a meeting held at Sheffield Hallam University. The universities that returned data were Nottingham Trent University, University of Greenwich, University of Reading, Salford University and Sheffield Hallam University. A questionnaire was planned to collect students' perceptions about the Maths Arcade and its impact on their university experience, socially and academically, while providing some practical information for those running Arcades, such as around ideas for increasing attendance. Between the different universities, the Maths Arcades are operated in different ways, so the survey questions had to be sufficiently inclusive of these differences, while enabling a comparison between participating universities.

The intention was to hand out the questionnaire on paper during lectures, to maximise the number of replies and enable collection of data from non-attenders and those with infrequent attendance. Therefore, a question asked how often respondents attended the Maths Arcade, with options 'never', 'once', 'a few times' and 'most weeks'.

In fact, due to time constraints at the end of the academic year, two of the five universities were only able to distribute the questionnaire at a Maths Arcade session, reducing the presence of the non- and infrequent-attender voice in the data. The other three universities distributed questionnaires during lectures attended by a cross-section of attending and non-attending students. An online version of the questionnaire was considered, but it was felt this would attract fewer responses and making both available in parallel risked double-counting.

Practical questions aimed particularly at helping staff understand the running of their Arcade and how this might be improved included degree course, year of study and free-text questions 'What would encourage you to come to the Maths Arcade more often?', 'What is your favourite Maths Arcade game and why?' and 'What are the best and worst things about the Maths Arcade?'.

Questions aimed particularly at identifying students' views on the impact of the Maths Arcade on their university experience, aligned to the social aims of setting up a Maths Arcade (Bradshaw, 2011), were 'Have you made any new friends through the Maths Arcade?' (yes/no) and 'Do you think staff should attend the Maths Arcade more or less? Why?' (free-text).

4. Results

The questionnaire received 295 responses. By university, these were: Nottingham Trent University (101), University of Greenwich (72), University of Reading (102), Salford University (14) and Sheffield Hallam University (6). Of these, 124 were from students who had attended the Maths Arcade. By university: Nottingham Trent University (25), University of Greenwich (65), University of Reading (18), Salford University (12) and Sheffield Hallam University (6). A breakdown of responses by frequency in included in table 1.

Frequency	**Responses**
Most weeks	38 (13%)
A few times	56 (19%)
Once	30 (10%)
Never	169 (57%)
Unanswered	2 (1%)

Table 1: How often respondents attended the Maths Arcade.

From 124 students who had attended, 58 indicated that they had made friends at the Maths Arcade, 59 had not and seven did not answer the question. Table 2 gives a breakdown by attendance frequency, indicating that the students who attended more frequently more often made friends.

Attendance frequency	**Yes**	**No**
Most weeks	26 (70%)	11 (30%)
A few times	27 (51%)	26 (49%)
Once	5 (19%)	22 (81%)

Table 2: Whether students made friends at the Maths Arcade, by attendance frequency.

149 students answered the question about staff attendance, including 56 who had not indicated that they attend the Maths Arcade. Most students who answered said they would like staff to attend more often. A breakdown is given in table 3. For the seven who wanted staff to attend less often, only three had indicated that they had attended the Maths Arcade and the most common free-text response was that a student-only event would be less formal. For the 24 who suggested the same level of staff attendance, most did not give a reason but one indicated this was a choice for lecturers to make. The most common reasons for wanting staff to attend more were that this improves the staff-student relationship (37 responses) and that staff presence is helpful (33).

Staff attendance preference	**Responses**
More	118 (79%)
Less	7 (5%)
Same	24 (16%)

Table 3: Whether students wanted staff to attend more or less often.

The free-text question about what would encourage students to attend more often was answered by 209 students. These responses were grouped into categories, with some responses placed in more than one category, meaning that 235 responses are recorded. The data contains 101 reasons given by 88 students who indicated that they had attended the Maths Arcade and 134 reasons from 121 students who had not indicated that they had attended the Maths Arcade. A breakdown by attendance frequency is given in table 4.

The most frequent response was to highlight an issue with the timing of the Maths Arcade, usually either that this clashes with a sporting activity or that the gap between contact hours and the Arcade is so large that students do not stay at university for the Arcade. Responses to the question about the 'worse' things about the Maths Arcade also focused on these issues, with timetabling a particular issue.

Reason	**Most weeks**	**A few times**	**Once**	**Non-attenders**	**Total**
Different time	1 (4%)	14 (27%)	11 (42%)	33 (25%)	59 (25%)
Food	7 (29%)	8 (16%)	5 (19%)	32 (24%)	52 (22%)
Improved advertisement	0 (0%)	2 (4%)	3 (12%)	30 (22%)	35 (15%)
Different/more games	6 (25%)	7 (14%)	4 (15%)	6 (4%)	23 (10%)
Greater attendance level	2 (8%)	7 (14%)	2 (8%)	13 (10%)	24 (10%)
Help with academic work	3 (13%)	4 (8%)	0 (0%)	5 (4%)	12 (5%)
Competitions and other structured activities	0 (0%)	1 (2%)	0 (0%)	6 (4%)	7 (3%)
Incentives	1 (4%)	5 (10%)	0 (0%)	1 (1%)	7 (3%)
Other	4 (17%)	3 (6%)	1 (4%)	8 (6%)	16 (7%)

Table 4: Responses to 'What would encourage you to come to the Maths Arcade more often?'

Of those students who reported attending the Maths Arcade, 80 gave their favourite game; actually six of these gave two games, so that 86 responses are included. The most popular game overall was Quarto, with 11 out of 86 responses. The reasons given were mostly highlighting it as a challenging game. The numbers vary per university, however; for example, Ingenious is the most popular game at Sheffield Hallam University but does not feature in responses from any other university. Responses also vary according to attendance level. For example, Quarto was the most popular game among those attending 'most weeks' (9 responses), followed by Pentago (6 responses), while the most popular for those attending 'a few times' or 'once' was Blokus (10 responses), followed by Chess (7 responses). Chess is a game that is familiar to some students already. Blokus is a four-player game, meaning it may be easier for a group of friends to pick up and play even when they are not all frequent attenders.

The free-text question asking for the 'best' things about the Maths Arcade was answered by 76 students, all of whom had all attended the Maths Arcade, who gave 90 responses. The most common response was the games themselves, with 31 responses, and the social environment, with 19 responses.

5. Discussion

The Maths Arcade aims to support students, create a maths-themed staff-student community and develop mathematical thinking through strategy game-play.

The questionnaire attracted responses from students with a variety of attendance levels, giving confidence that the results represent different viewpoints. It should be noted that response rates varied per institution, with most attendee responses from University of Greenwich and most non-attendee responses from University of Reading.

The result that students who attended more frequently were more likely to make friends at the Maths Arcade is not surprising, but pleasing to see as building a mathematical community is one of the aims of the initiative. Almost three quarters of students would like to see more staff attendance, with many feeling this helps develop a staff-student community and that staff presence is helpful at the Arcade. Again this is pleasing as encouraging opportunities for staff/student interaction is one of the aims of the initiative.

Positives from the free-text feedback include students liking the games and enjoying the social environment. Negatives focused on practicalities, particularly the timing of sessions, and low attendance at some sessions. The former, finding a time that suits the different timetables for students in different year groups, is a difficult practical problem. Negotiation with those who arrange timetables gives the best chance of an amicable solution. The latter problem, students who are reluctant to attend because attendance is low, is difficult but ultimately self-fulfilling; hopefully if the timetable and advertising are well-organised, this problem will reduce.

Although numbers of responses were small, it is interesting to observe students who attend more frequently are drawn to the more challenging two-player games such as Quarto and Pentago than the four-player Blokus. As two-player games are more open to analysis, this promotes the idea that students may be moving from simply playing games towards analysis of strategy.

Funding

Webster's work on this project was funded by the Nottingham Trent University Scholarship Projects for Undergraduate Research (SPUR) scheme and supervised by Rowlett and Hind. An evaluation planning meeting was supported by Sheffield Hallam University.

References

Badger, M., Sangwin, C., Ventura-Medina, E. & Thomas, C.R. (2012). *A Guide to Puzzle-Based Learning in STEM Subjects*. Birmingham, U.K.: National HE STEM Programme.

Bradshaw, N. (2011) The University of Greenwich Maths Arcade. *MSOR Connections*, vol. 11(3), 26-29.

Bradshaw, N. & Rowlett, P. (Eds.) (2012). *Maths Arcade: stretching and supporting mathematical thinking*. Birmingham, U.K.: MSOR Network.

Butler, D. (2012). *4-Dimensional Noughts and Crosses*. Retrieved from https://www.adelaide.edu.au/mathslearning/play/4DOXRules.pdf

Carpenter, N. (2011). The University of Greenwich Maths Arcade – student view. *MSOR Connections*, vol. 11(3), 30.

Chadwick, E. (2012). University of Salford 'Maths Arcade' – As a project activity. In N. Bradshaw & P. Rowlett (Eds.), *Maths Arcade: stretching and supporting mathematical thinking* (p. 17). Birmingham, U.K.: MSOR Network.

Cliffe, E., White, J., Benjamin, L. & Lacey, C. (2012). University of Bath 'MASH Café' – Cross-disciplinary peer support and problem solving. In N. Bradshaw & P. Rowlett (Eds.), *Maths Arcade: stretching and supporting mathematical thinking* (p. 25). Birmingham, U.K.: MSOR Network.

Conway, J.H. (1976). *On Numbers and Games*. London, U.K.: Academic Press.

Cornock, C. & Baxter, E. (2012). Sheffield Hallam University 'Maths Arcade' – Feedback on a trial and plans to include in peer assisted learning. In N. Bradshaw & P. Rowlett (Eds.), *Maths Arcade: stretching and supporting mathematical thinking* (p. 19). Birmingham, U.K.: MSOR Network.

Croft, T. & Grove, M. (2015). Progression within the mathematics curriculum. In M. Grove, T. Croft, J. Kyle & D. Lawson (Eds.), *Transitions in Undergraduate Mathematics Education* (pp. 173-189). Birmingham, U.K.: University of Birmingham.

Gardner, M. (1959). *The Scientific American Book of Mathematical Puzzles and Diversions*. New York: Simon and Schuster.

Gough, J. (2015). New games that stimulate mathematical thinking. *The Australian Mathematics Teacher*, vol. 71(1), 24-27.

Lawson, D. (2015). Mathematics Support at the transition to university. In M. Grove, T. Croft, J. Kyle & D. Lawson (Eds.), *Transitions in Undergraduate Mathematics Education* (pp. 39-56). Birmingham, U.K.: University of Birmingham.

QAA [The Quality Assurance Agency for Higher Education] (2015). *Subject Benchmark Statement: Mathematics, Statistics and Operational Research*. Gloucester, U.K.: The Quality Assurance Agency for Higher Education.

Rowlett, P. (2015). Developing Strategic and Mathematical Thinking via Game Play: Programming to Investigate a Risky Strategy for Quarto. *The Mathematics Enthusiast*, vol. 12(1, 2 & 3), 55-61.

Trowler, V. & Trowler, P. (2010). *Student engagement evidence summary*. York, U.K.: The Higher Education Academy.

Webster, K. & Rowlett, P. (2013). A Maths Arcade at Nottingham Trent University. *Mathematics Today*, vol. 49, 120.

B. Tomorrow's Mathematicians Today undergraduate conference.

B1. TMT website.

Tomorrow's Mathematicians Today, 2018. *Origins of TMT*. [online] Available at: https://sites.google.com/site/imatmt2019/origins-of-tmt [Accessed 15 September 2018].

B2. TMT Compass article.

Bradshaw, N., 2012. Undergraduates Speak Out! Undergraduate Mathematics Conference: Tomorrow's Mathematicians Today. *Compass: Journal of Learning and Teaching*, 3(4). Available at: https://journals.gre.ac.uk/index.php/compass/article/view/55/91 [Accessed 15 September 2018].

B3. TMT Conference report.

Ellis, N., 2017. Tomorrow's Mathematicians Today Conference Report. Manchester, UK, February 2017. Available at: https://www2.mmu.ac.uk/media/mmuacuk/content/documents/school-of-computing-mathematics-and-digital-technology/tmt17/TMT-2017-Conference-Report-v2.pdf [Accessed 15 September 2018].

B4. Quotations from TMT conferences.

Tomorrow's Mathematicians Today, 2016. *Quotes from past TMT conferences*. [online] Available at: http://mathsoc.cms.gre.ac.uk/tmt/Quotes.html [Accessed 5 July 2018].

C. Employability Initiatives

C1. IMA Business Game

Wolfin, S. (2016). IMA Business Game at University of Greenwich. *MSOR Connections*, 14(2), 34-36. Available at: https://journals.gre.ac.uk/index.php/msor/article/view/288/296 [Accessed 12 March 2016]

C2. PDP Assessment

Bradshaw, N., 2014. *Employer-endorsed employability assessment: An assignment delivered in an Operational Research course to second year mathematics students*. HEA STEM. Available at: https://www.heacademy.ac.uk/sites/default/files/resources/msor-130-paper.pdf [Accessed 13 March 2016]

C3. Maths Grads: Where are they now?

Bradshaw, N., 2012a. Maths Graduates: Where are they now? In: P. Rowlett, ed. 2012. *Further Work Developing Graduate Skills in HE Mathematics Programmes.* Birmingham, UK: HESTEM. pp.10-11. Available at: http://www.mathcentre.ac.uk/resources/uploaded/furthergradskills.pdf [Accessed 25 September 2018].

C4. New Data Analytics Module

Bradshaw, N. and Nicholas, B., 2017. A combination of industry collaboration and flipped classroom to increase learners' confidence and skillset. In: CETL-MSOR, *CETL-MSOR Conference 2016*: *A Brave New World.* Loughborough University, 6-7 September 2016. Birmingham: **sigma**. pp.10-16. Available at: http://www.sigma-network.ac.uk/wp-content/uploads/2016/11/CETL-MSOR-Proceedings-2016.pdf [Accessed 25 September 2018].

C5. Embedding Employability into the Curriculum

Bradshaw, N., 2016. Flipping Employability: Discovering how to further embed employability into the mathematics curriculum. Presented at The Higher Education Academy STEM conference, Nottingham, 28-29 January 2016. Available at:

https://www.heacademy.ac.uk/system/files/downloads/2.6_nabradshaw-flipping_employability.pdf

[Accessed 15 September 2018].

D. Screencasts and videos

D1. Conference paper from IMA Barriers and Enablers conference

Bradshaw, N., 2015a. The use of video and mathscasts to engage and support the learner and promote mathematical thinking. In: *IMA International Conference on Barriers and Enablers to Learning Math,* Glasgow. Available at: https://cdn.ima.org.uk/wp/wp-content/uploads/2015/06/The-use-of-video-and-screen-casts-to-engage-and-support-the-learner-and-promote-mathematical-thinking.pdf [Accessed 15 September 2018].

D2. Presentation from University of Greenwich conference

Bradshaw, N., 2013. Encouraging Students to Think Using Online Learning Resources. *University of Greenwich Teaching and Learning Conference*. London July 2013. Available at: https://showtime.gre.ac.uk/index.php/edu/sp/schedConf/presentations [Accessed 15 September 2018].

D3. Employability videos

D3.1 Paper.

Bradshaw, N., 2016. Creating videos to assist students' understanding of the graduate recruitment process. *Compass: Journal of Learning and Teaching*, 8(12). Available at: https://journals.gre.ac.uk/index.php/compass/article/view/274/319 [Accessed 15 September 2018].

D3.2 Successful interviews.

Bradshaw, N., 2015b. *Good job interviews*. [video online]. Available at: https://www.youtube.com/playlist?list=PL5ybYlTaCtx4rlmkTOdQZy-2vVtp03nFg [Accessed 12 March 2016]

D3.3 Poor interviews.

Bradshaw, N., 2015c. *Poor job interviews*. [video online]. Available at:

https://www.youtube.com/playlist?list=PL5ybYlTaCtx6W5nSkT1cCehJssjha0iix [Accessed 12 March 2016].

E. Other evidence

E1. MSOR Connections.

Bradshaw, N., ed.,2016. *MSOR Connections*, 14(3). Available at:

https://193.60.48.124/index.php/msor/issue/viewIssue/44/27 [Accessed 25 September 2018].

E2. MSOR Connections.

Bradshaw, N., ed.,2018. *MSOR Connections*, 15(1). Available at:

https://193.60.48.124/index.php/msor/issue/viewIssue/47/37 [Accessed 25 September 2018].

E3. Chapter on Florence Nightingale.

Bradshaw, N., 2017. Florence Nightingale (1820–1910): A Pioneer of Data Visualisation. In: J.L. Beery, S.J. Greenwald, J.A. Jensen-Vallin and M.B. Mast eds. *Women in Mathematics,* Association for Women in Mathematics Series, 10. Cham, Switzerland: Springer. Ch. 11.

Chapter 11
Florence Nightingale (1820–1910): A Pioneer of Data Visualisation

Noel-Ann Bradshaw

Abstract In this chapter Florence Nightingale is positioned not just as a mathematician and statistician but also as a forerunner of the modern-day areas now known as operational research and data science. The chapter begins by examining the influences in Nightingale's early life which led to her interest in, and aptitude for, mathematics and statistics. A selection of the various detailed data charts that she created in order to influence political decision making is discussed. Following on from her charts, Nightingale's commentary on some of the statistical calculations and data management by army officials during and after the Crimean War is presented and there is discussion on the enormous impact of her work on the mortality rate of soldiers in the British Army and her subsequent significant influence on the reorganisation of army medical statistics.

Keywords Florence Nightingale • Statistics • Data analysis • Statistical figures • Operations research • Data science

11.1 Introduction

For most people today the name "Florence Nightingale" will conjure up a picture of "The Lady with the Lamp" in the Crimean War (1853–1856) and bring to mind her contribution to nursing. However, whilst she was indeed heavily involved in practical nursing, her contribution to the medical world went far beyond these nursing skills and even the training of new nurses [2]. Her knowledge and understanding of mathematics and the correct use of statistics led to her being able to comment usefully on the numerous inaccuracies in the data that were collected and reported on during the Crimean War. Her ground-breaking work in this area continued after she returned to England and, as a result of her influence, great changes took place in the organisation and reporting of British military statistics both in the UK and in the British colonies [15]. Her work did not end with the armed forces. She also

N.-A. Bradshaw (✉)
Old Royal Naval College, University of Greenwich, London, UK
e-mail: N.Bradshaw@greenwich.ac.uk

© The Author(s) and the Association for Women in Mathematics 2017

J.L. Beery et al. (eds.), *Women in Mathematics*, Association for Women in Mathematics Series 10, https://doi.org/10.1007/978-3-319-66694-5_11

Fig. 11.1 Portrait of Florence Nightingale [40]

played a pivotal role in the improvement of conditions for those in workhouses and for the working classes in general. It was her unusually deep understanding of data and statistics that led her to set up various training programs for nurses and district nurses in England [18]. This chapter will examine how Nightingale (Fig. 11.1) used her quantitative skills to bring about change to the areas of society about which she was so passionate.

11.2 Early Influences

> I can never be sufficiently thankful to Papa for having given me an interest in Statistical and Political matters [24].

Florence Nightingale was born in the city of Florence, Italy, on May 12, 1820, to William and Fanny Nightingale. Her sister, Parthenope, had been born in the previous year in Naples. After Florence's birth, the family moved back to England. They initially settled at Lea Hurst in Derbyshire but then purchased an estate, Embley Park, in Embley, Hampshire, where they ended up residing during the winter months as Fanny found the Derbyshire climate too harsh. William Nightingale had been the recipient of a large inheritance at the age of 10 so did not need to work in order to support himself and his family [1]. The family was highly regarded amongst the upper echelons of society and, as a result, they mixed with intellectuals and political movers and shakers of the day including Charles Darwin and Lord Byron [1]. The noted Nightingale biographer, Mark Bostridge [1], added that Byron's daughter, Ada Lovelace, was befriended by Nightingale and her sister, and a contemporary biographer, Edward Cook, reproduced a poem that Lovelace wrote about Florence, "Should war's dread strife its victims claim" [3].

Nightingale was an avid letter writer from a young age. Many of her letters still exist and show the sort of upbringing and education she had. She appears to have been a quite studious child with a keen sense of fairness and a head for order and number. An example of this is a letter written when aged 8 to her grandmother after a trip to a zoo in which she listed all the animals she had seen and recounted how many there were of each species [22]. In a letter to her sister, who was away with their mother, she described the organisation of the pantry and tabulated how certain fruits and vegetables were categorised [23].[1]

Nightingale's education was supervised by her father, who was keen that both his daughters should learn academic subjects as well as gain the variety of accomplishments, such as drawing and needlework, that Victorians expected of females in society. She had a great passion for learning; several of her early letters to her mother and sister are written in French and testify to her language skills [20]. There are many anecdotes from friends and family members mentioning her accomplishments in Latin and Greek. A particularly nice example is recorded in the journal of a cousin of the social reformer Elizabeth Fry. It describes a dinner party where the man sitting beside Nightingale was heard to comment afterwards, "a capital young lady that if she hadn't floored me with her Latin and Greek" [1].

When Nightingale was about 18, her sister wrote: "Florence has taken to mathematics - and like everything else she undertakes she is deep in them and working very hard" [1]. Like many mathematicians, it seems that Nightingale put her all into her pursuit of the subject. Bostridge [1] described an occasion where her cousin Henry Nicholson (who was studying mathematics at Trinity College, Cambridge) came to stay at Lea Hurst while the family were in the process of moving to Embley Park. Oblivious to the chaos around them, Nightingale and Nicholson "soon became absorbed in logarithms" [1].

This interest in mathematics led Nightingale to read and comment on the work of Lambert Adolphe Jacques Quetelet, the Belgian statistician whom she was to eventually meet in 1860, when he chaired the International Statistical Congress (ISC) in London and after which they kept up a lively correspondence [5]. What initially started as an interest and a pastime was later to become a pivotal tool which Nightingale used to gain influence and bring about change.

[1]These and many other letters can be found in the collections at the Wellcome library [40] or read online via Professor McDonald's project: *The Collected Works of Florence Nightingale* [21].

As a young adult Nightingale struggled with depression, possibly caused by a lack of a perceived purpose. She wanted to work and do something more with her life rather than settle for getting married and having a family. This ambition was frowned upon by her parents and other family members [1]. She had taken part in several trips to the Continent and it was while in Germany that she spent some time at a hospital in Kaiserswerth. Here she developed a friendship with the Lutheran pastor Theodore Fliedners who had established the Institution of Deaconesses, which included a hospital, some years before [1]. From working with Fliedners and his second wife Caroline during several prolonged visits, Nightingale learned much about nursing and hospital management [1]. As a result of this training, she put forward a number of proposals for a career in nursing to her parents. However, they were initially unsupportive as nursing was generally not thought to be a respectable profession and especially so for someone of their social standing. It was also on one of her continental trips that she met Sidney and Elizabeth Herbert, a couple who were going to greatly influence the course of her life [1].

Despite Florence being very close to her sister when they were young, their relationship became strained as they grew older and eventually, for the sake of family peace and Parthenope's health, it became necessary for Florence to live independently. Reluctantly, her parents allowed her to work as the superintendent of a home for gentlewomen in London's Harley Street in early 1853 [1]. Not long after Florence had gained independence from her family, the Crimean War broke out in October 1853. Florence immediately wrote to Sidney Herbert (who was then Secretary at War) offering her services, while at exactly the same time Herbert wrote to Florence asking (or, according to Parthenope, "entreating") Florence to travel to the Crimea and assist in tackling the medical chaos which was just starting to be reported [3].

The remainder of this chapter will show how Nightingale used her time in the Crimea to gather the evidence and experience which enabled her to help reorganise the medical statistics in the British Army and to make a huge contribution to government policy and public understanding of statistics and data management. Nightingale's nursing work and her reorganisation of supplies in the Crimea will not be discussed as there are many detailed accounts of this elsewhere, such as [1] and [19].

11.3 The Use of Visual Representations

> Diagrams are of great utility for understanding certain questions of vital statistics [29].

Nightingale was in the Crimea for just under two years, from Autumn 1854 to Summer 1856. In this short time she managed to reorganise the military hospitals and oversee the arrival and work of the Royal Commission on the Sanitary Condition of the Army in March 1855 (headed by Dr. John Sutherland who was to become one of her closest advisors). She was subsequently asked to contribute to the Royal

Commission's final report. Whilst in the Crimea she communicated with many influential people in the British government and society in order to highlight the plight of the soldiers and to raise awareness of the poor organisation of military statistics [1].

Shortly before Nightingale left the Crimea she became ill. This illness never left her and she remained an invalid until her death in 1910. Some of her biographers have referred to her as a malingerer as there was no documented diagnosis of her condition, but others say that her reported symptoms suggest that she is likely to have suffered from brucellosis [6] or spondylitis [1]. However, despite her illness, and days when she described herself as "entirely a prisoner to my bed" [27], throughout the remainder of her long life she produced numerous papers and reports and successfully lobbied government on a wide variety of issues – from the health of the British Army in England and India to the condition of the poor and mentally ill living in workhouses [1].

In Autumn 1856, just after her return from the Crimea, as a result of an audience with Queen Victoria and a subsequent meeting with the new Secretary of State for War, Lord Panmure, Nightingale was asked to draw up a list of potential members for a new Royal Commission to investigate the state of the British Army's whole medical department both at home and abroad [1]. Panmure also requested her to write a confidential report to enable him to "further her views" on the sanitary requirements of the army [36]. The result was a lengthy report, *Notes on Matters Affecting the Health, Efficiency and Hospital Administration of the British Army* [30], accompanied by a pamphlet mainly containing diagrams and tables of data [29] which had been reproduced from the appendix to the Report of the Royal Commission. Initially confidential, it was later distributed to a variety of public figures [19] but not formally published [12]. The first draft of the report was 567 pages but a later preface by Nightingale indicates that she received a large amount of new material which she inserted into the beginning of several chapters. The original pages of the report have Arabic numbers but the additional pages have Roman numerals which are duplicated in each section. The resulting 853 pages, as McDonald noted, are "extremely difficult to follow", but nonetheless make for fascinating reading [19].

Nightingale's pamphlet of diagrams, referred to by Herbert as her "Coxcomb" [35], was publicised more widely. In a letter to Herbert on Christmas Day 1857 [26], she concluded that she didn't think anyone would read the tables and diagrams, despite her foreword to the Coxcomb saying, "Diagrams are of great utility for understanding certain questions of vital statistics by conveying ideas on the subject through the eye which cannot be so readily grasped when contained in figures" [29]. Yet she went on to compile a lengthy list of categories of people who should receive it, including Queen Victoria.

Nightingale was aware of William Playfair's use of diagrams to persuade and campaign within the commercial world [11]. Playfair's pie charts and line graphs seem to have influenced Nightingale's use of what are now known as infographics. Her main report contains the three well-known polar area diagrams known to Nightingale as "Wedges", two of which are reproduced here (Figures 11.2 and 11.3).

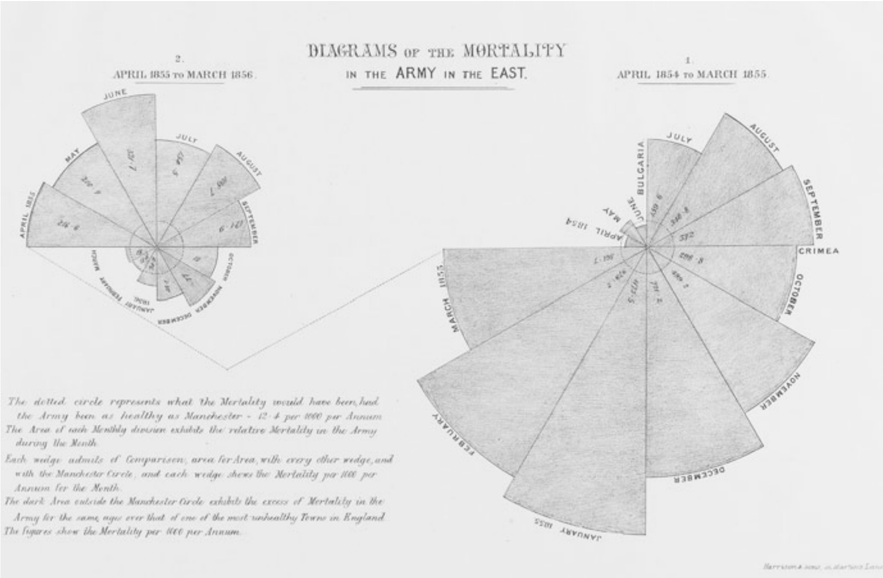

Fig. 11.2 Diagrams of the Mortality in the Army in the East [40]

These polar area diagrams were already being utilised extensively by Quetelet and André-Michel Guerry (a French lawyer and statistician) and were commented on and reproduced by Friendly [9]. It is interesting to note that the data Nightingale depicted works particularly well when portrayed in polar area diagrams, but, because of the large range of the data, they do not transfer well to the bar or line graphs that Nightingale used elsewhere. It would also be very difficult to clearly show the comparison with Manchester in Figure 11.2 on a standard pie chart.

In Figure 11.2, Nightingale has graphed the mortality rate from April 1854 to March 1856. The inner circle on each polar diagram represents the average mortality rate in Manchester, which Nightingale referred to as "one of the most unhealthy towns in England". This comparison immediately grabs the reader's attention and cleverly illustrates the extent of the problem in the Crimea. The diagrams in Figure 11.2 show that after the introduction of the Sanitary Commission, from March 1855, the mortality rate started decreasing.

In Figure 11.3 Nightingale has used the same underlying data as in Figure 11.2 but this time she has introduced coloured wedges to compare the different mortality rates from different causes of death. The blue wedges represent deaths from zymotic diseases (such as cholera and typhoid), the red wedges deaths from wounds and the black wedges deaths from all other causes. All wedges are measured from the centre.

The Coxcomb also contains two diagrams that Nightingale referred to as having large areas that looked like "a great black bat's wing" [29]. However, Nightingale realised that the diagrams in Figures 11.4 and 11.5 were open to misinterpretation and later editions of the Coxcomb contain a note emphasising that, in these

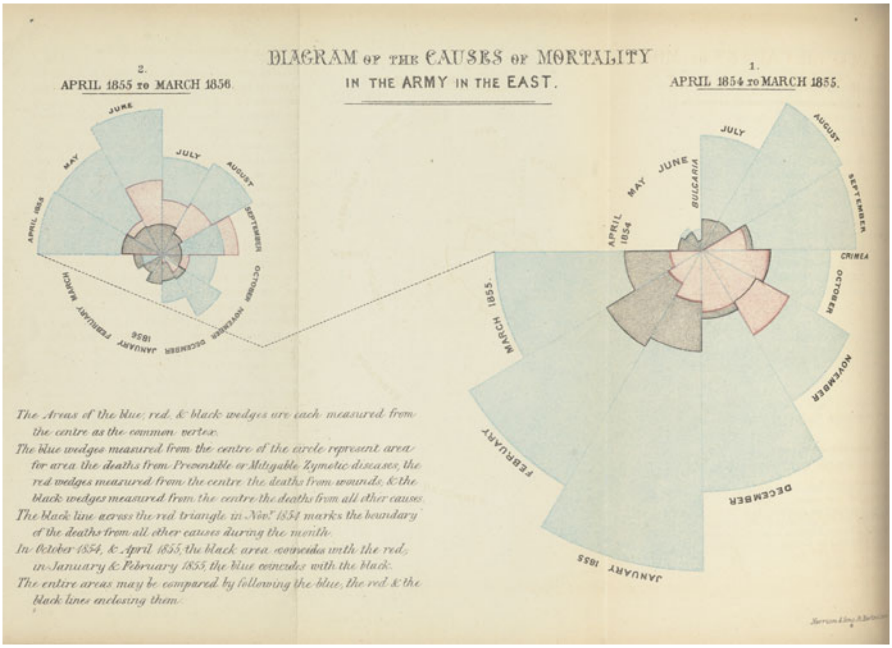

Fig. 11.3 Diagram of the Causes of Mortality in the Army in the East [40]

diagrams, it is the "radial lines . . . which shows the mortality for a particular month" and that the radii have only been joined and shaded to "impress upon the eye more clearly the rise, decline and extent of the mortality". She emphasised this by concluding that "it is not intended that the larger area should be contrasted with the smaller but simply the longer with the shorter line". It appears that Nightingale did not think this note was strictly necessary as in a letter to her sister in 1858 she complained that there was no mistake and it was only "ignorant people [who] conceive that the comparison is intended to be between the areas" [28]. However, in the same letter she conceded that those diagrams in her report that compared areas were "more mathematically correct".

The first of these "bat-wing" diagrams (Figure 11.4) is similar to Figure 11.2 in that it compares the mortality rate of the army with that in Manchester. Nightingale noted that the diagram shows how healthy the army was on arrival in the Crimea and that the rapid rise in the mortality rate during January 1855 was greater than that during the Great Plague of London in September 1665. She went on to explain that the diagram gives a pictorial representation of the great Crimean calamity during the first year of the war and then later added that this diagram means that "we have at a glance the vital statistics of the Crimean War" [29]. This shows her understanding of the power of data visualisation, something that we shall see later was not yet appreciated by many in the UK.

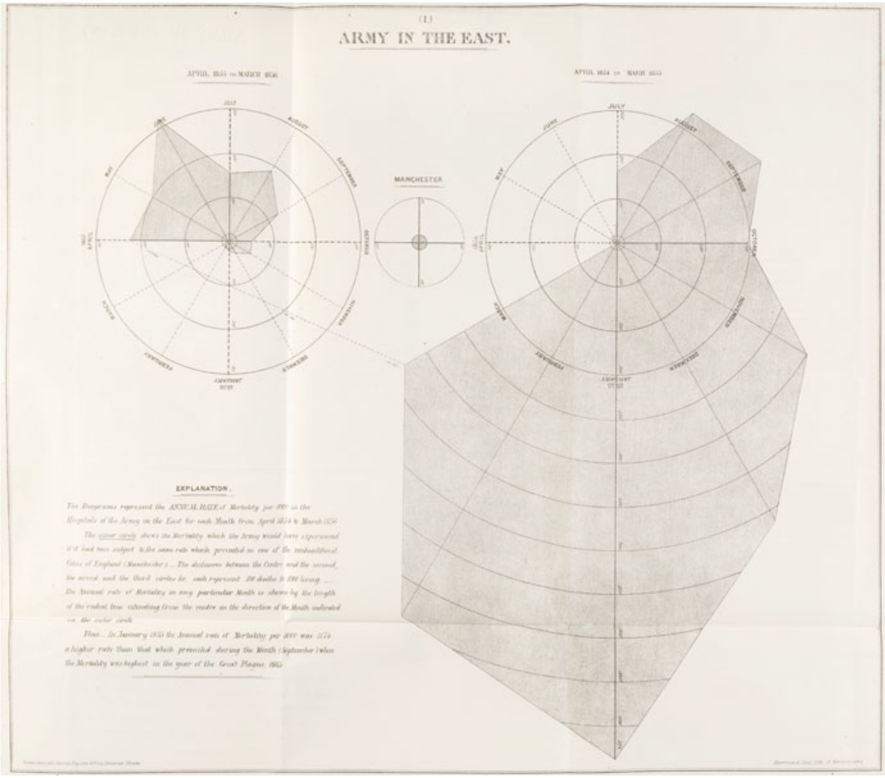

Fig. 11.4 Diagrams representing the Relative Mortality in the Hospitals in the Army in the East [40]

The second of these diagrams, Figure 11.5, is similar to Figure 11.2 in its use of colour to depict the causes of death. Nightingale explained that this diagram at a glance shows that zymotic diseases (coloured green) were "the cause of the whole catastrophe" [29]. Again, red is used for wounds and black for deaths from other causes.

Nightingale was well acquainted with the statistician William Farr and worked closely with him on several occasions. In his role as Chief Statistician in the General Register Office, he introduced statistical diagrams into the *Journal of the Royal Statistical Society* (RSS), but they were not always well received in Britain despite being used extensively in Europe. According to Cullen [4], Guerry's early work, containing several coloured diagrams, was considered heretical. Farr himself remained suspicious of representing data in pictorial form saying at one point that statistics should be "the dryest [*sic*] of all reading" and complaining that Nightingale's attempts were not "sufficiently dry" despite her worrying that they were too dry [8]. It is clear that she did not agree with this as she was keen to use diagrams to ensure that the data was clearly understood. There is no indication that

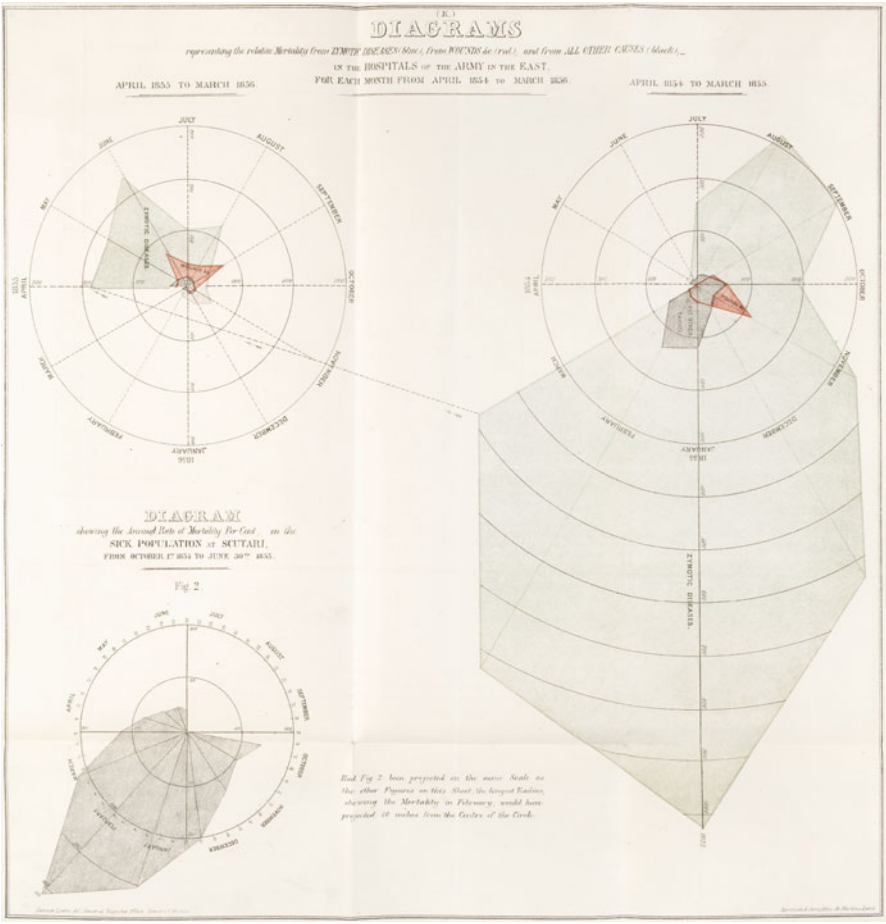

Fig. 11.5 Diagrams representing the Relative Mortality from Zymotic Diseases, Wounds, and from all other causes in the Hospitals of the Army in the East

Nightingale made any attempt to address Farr's comments. Readers interested in a more detailed commentary on other statistical diagrams of the period might like to consult the article by Magnello [14].

Nightingale also used a variety of other diagrams to portray data. Her Coxcomb contains several line graphs comparing the mortality rate of the British Army at rest with the mortality rate for the male civic population. These diagrams make it abundantly clear that there was something seriously amiss given, as Nightingale pointed out, that the soldiers entered the army in "peak physical fitness" [29] and yet when they became ill their chances of recovery were lower than for those living in densely populated areas of England.

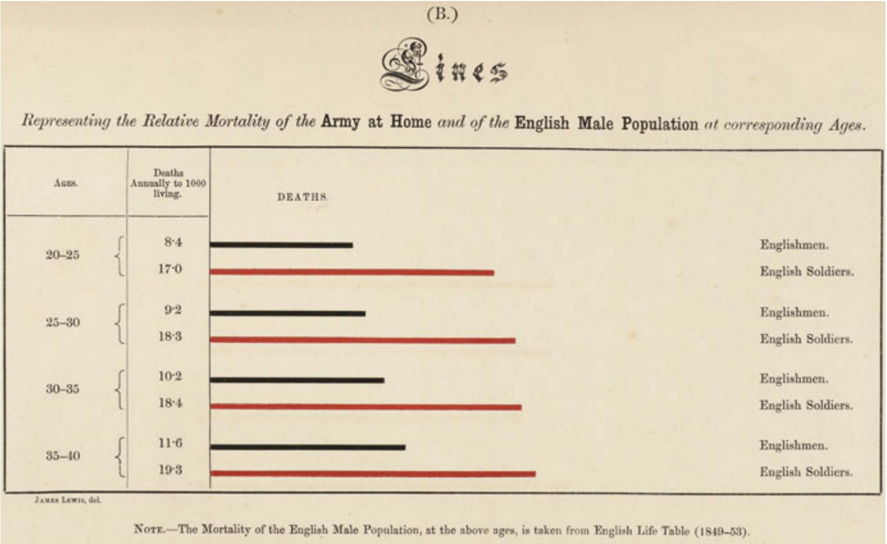

Fig. 11.6 Line graph representing the Relative Mortality of the Army at Home and of the English Male Population [40]

In Figure 11.6 the black lines denote the mortality in the general English male population and the red lines the mortality in the army on home service. Nightingale discussed this diagram at some length, echoing many of her comments from the main report. These discussions are summarised in the next section of this chapter.

Having clearly demonstrated in Figure 11.6 the differences in the mortality rates, Nightingale then constructed a variation of a bar chart to clearly show the causes of the deaths (Figure 11.7). She described these diagrams as representing the "classes of mortality from disease most prevalent in the infantry as compared with the same types of disease in civil life at the same age", noting that they "exhibit the frightful mortality continually going on in the British Army" [29]. She continued at some length to ask several pertinent questions such as "what can be the cause of all this?" before concluding that the issues were with overcrowding, poor ventilation and bad sanitation in the barracks [29]. These issues are highlighted in more detail in her main report [30] and later in this chapter.

Nightingale used the remaining two diagrams in the Coxcomb to make an even stronger political point. Firstly, in Figure 11.8 she created an unusual hexagonal representation of area which graphed the population density of a proposed army camp and compared it to known densely populated parts of London. This illustrated the Quartermaster General's plans for encamping an 850-strong battalion. Nightingale depicted the number of tents in each row of the plan and, consequently, calculated the occupied area. She noted that "it has been found that sickness and mortality bear a certain ratio to the density", with the most populated towns being the most unhealthy [29]. She then compared the density of the populations

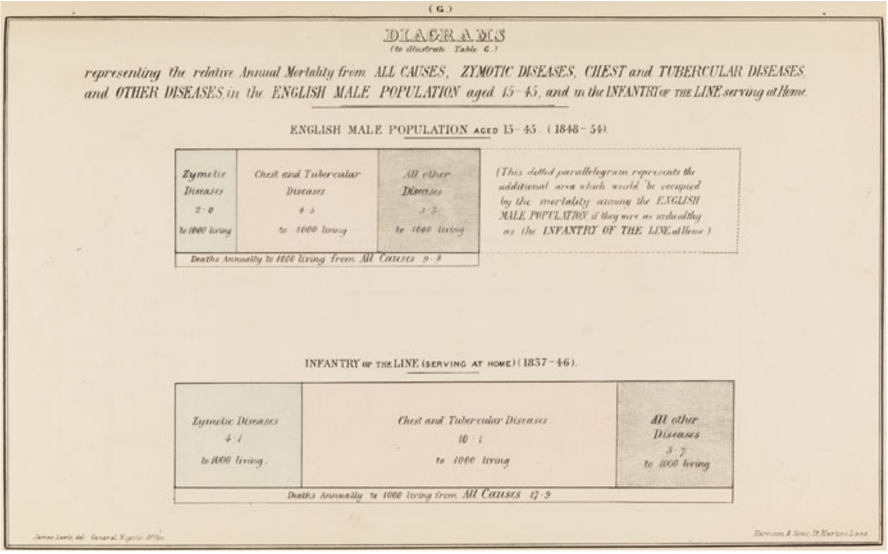

Fig. 11.7 Diagrams representing the Relative Annual Mortality from all causes, Zymotic Diseases, Chest and Tubercular Diseases and other Diseases in the English Male Population aged 15–45, and in the Infantry of the Line serving at Home [40]

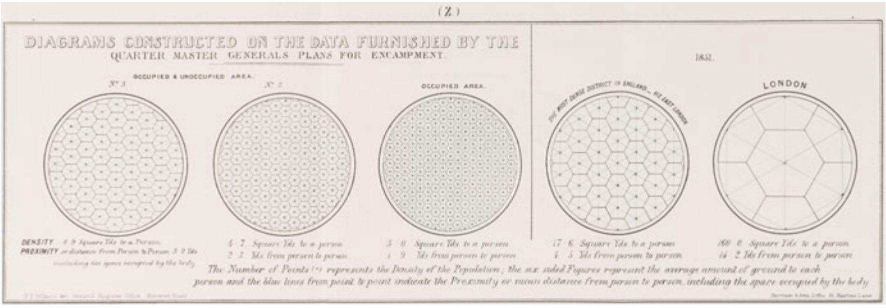

Fig. 11.8 Diagrams constructed on the Data Furnished by the Quarter Master General's Plans for Encampment [40]

in these encampments with the most densely populated part of London and the whole of London (built and unbuilt). She concluded that "these comparisons will be sufficient to show the great importance of this element of overcrowding to the health of camps" [29]. Interestingly this diagram has a whole section to itself and is labelled as Diagram Z whereas the other diagrams are labelled A-K, perhaps showing the significance that Nightingale understandably felt it deserved. After the brief description of the diagram, Nightingale provided various calculations reinforcing the issue and concluded that the "least crowded of the Quartermaster General's plans affords about a twentieth part of the area per man allotted to each

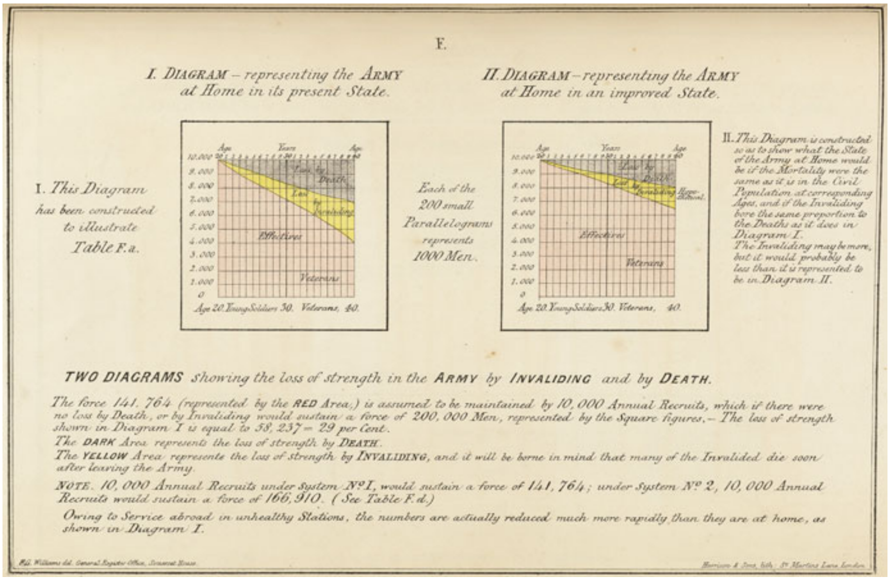

Fig. 11.9 Diagrams showing the loss of strength in the Army by Invaliding and by Death [40]

inhabitant of the metropolis; that it is about half the amount of that of the most densely peopled part of London; and that the population on the occupied area of the camp is above 50 times more crowded than the population of London" [29]. This beautifully understated punchline demonstrates what Nightingale was so adept at; clearly illuminating the fallacy of someone's decision with a simple comparative diagram or worked-through calculation.

Figure 11.9 shows a diagram where Nightingale attempted to forecast the expected health of the British Army had the soldiers been as healthy as the general British male population. This was an unfamiliar technique at the time and something that she had worked on with Farr. The black wedge represents the loss from deaths and the yellow wedge that from invaliding. She said that "by comparing the red areas of both diagrams the great loss of efficiency in the army in its present state becomes more apparent" [29]. She went on to comment that these diagrams "show the loss of life, of service and of money value entailed on the country by the neglect of sanitary measures in the army in time of peace" [29].

It is clear from the variety of graphs and diagrams and her correspondence that Nightingale was keen to ensure the optimal presentation for each set of data was used, and that the diagrams were mathematically correct [28]. Her diagrams appear to have been very ahead of their time. The accompanying commentary demonstrates how Nightingale's thinking was progressing, and how she was trying to use her diagrams to influence government policy and decision making. The use of data and quantitative methods in decision making is at the heart of what is now called Operational Research in the UK and Operations Research in the US.

11.4 The Use of Numbers

> Numbers teach us whether the world is well or ill governed [7].

Nightingale used data to find out what was happening in a given situation and then presented her findings in a variety of formats, pictorial and written. She worked with Farr on many projects and, in a letter from him in 1857, he suggested that a quote from Goethe, “Numbers teach us whether the world is well or ill governed”, should be their motto [7].

During her time in the Crimea, Nightingale wrote many letters to various officials and politicians as well as to family members. In much of this correspondence, she commented on errors in mathematical and statistical calculations as well as on poor data collection and organisation. A vast number of letters are included in her report on the Crimea [30]. The following excerpts from some of these letters show Nightingale’s attention to detail, her grasp of mathematics and statistics, and her passion for seeing this portrayed correctly and relevantly to different audiences in order to change the way they thought.

In July 1855, a letter from the Commandant for the Official Information of Her Majesty’s Government reported that “Sickness has very much diminished and so has mortality” [30]. Nightingale was appalled by the erroneous figures being used to show that the mortality rate was decreasing when it was in fact increasing and pointed out that stating the number of deaths each month is meaningless without the total hospital population being quoted and the numbers given as a percentage. So, although the death toll was decreasing, she went on to show that the rate of mortality was actually increasing enormously. Nightingale described this as being “like the celebrated riddle ‘Given the height of the mast to tell the captains name’.” In other words, the Commandant had not provided sufficient information to enable the reader to ascertain the required answer. In a similar discussion, further on in the report, she cautioned that this misuse of data “gives the Secretary of State no account of his accumulated loss” [30].

Other letters illustrating Nightingale’s concern with data can be found in the Wellcome Library, London [40]. A letter to John Henry Lefroy, scientist and military reformer, in June 1856, mentioned the medical statistics of the Land Transport Corps (a branch of the army which transported military supplies), describing them as being in “a state of great confusion, so that it is hardly possible to obtain correct results” [25]. Nightingale asserted the Corps had “an extraordinary method (or no method) of keeping statistics”. She explained that one of the problems was that sometimes the natives were included in the data and sometimes not, so there was no consistency. In a letter to Lady Canning (1856) [19], she was even more unguarded in her criticism: “I could make you laugh at our classification which seems to deceive and bamboozle government as to the cause of our disease . . . I think, if you could see our real statistics, you would think that I have been moderate in my statements”.

Nightingale was concerned that one of the issues was that neither the doctors nor the government officials had the skills necessary to understand the situation and thus advise on appropriate measures to see the mortality levels decrease. In a very long letter to Lord Grey in 1857 [19], she suggested several skills that a proposed new sanitary advisor should have but then concluded, at some length, that she could not see how one person could possess all these traits. She also scoffed at the notion that the new statistical officers and sanitary officers should be the same persons: "the distinction between these two departments is an important and a practical one, as much as the distinction between food and a cookery book" [19].

Her impatience with incompetent officials and badly designed systems is particularly apparent in a letter to Sidney Herbert in August 1857 [19], where she vented her frustration while awaiting the arrival of important data. When she eventually obtained the data, she used it to work out the mortality of those individuals who had been invalided out of the army. She argued that this data must be included in the final mortality figures because "the state loses them equally whether they die or are invalided before their term of service is completed – to have kept back this data shows either utter ignorance of the importance of their bearing, or a wilful intention to keep back the truth". She then described various methods of including this data correctly and provided numerical examples of the differences this additional data made to the reported figures. In a private note to Herbert in the same missive, she confided: "The army statistics give no real idea of the mortality. There is this essential difference between the Registrar-General's and the army's medical returns. The first give the precise percentage of deaths to population within the army ages. The second give no precise percentage of deaths to army population" [19]. This criticism of army medical data and the process of data collection, as well as her suggestions of more rigorous methods, was pivotal in changing the way that British military data was gathered and recorded.

Her report on the Crimean War [30] contained a lengthy commentary on the comparative mortality rates between the general male population and the army at rest (i.e., not in battle). She explained that for the ordinary civic population aged 20–40 years and living in London the mortality rate was 8 in 1000, the rate for the Metropolitan Police was also 8 in 1000, the rate for those in English jails doubled to 16 in 1000, whereas for the British Army it was between 17.8 and 20.4 in 1000. She also discussed at length the difference in the number of days that the average worker might be sick in one year compared to a soldier in the army, finding that the soldiers take more days off sick and thus render the army inefficient [30]. She was puzzled by this as the "guards are considered the finest obtainable troops" so it would seem that they should not have such a high mortality rate. She attributed this high mortality to the conditions in the barracks. Having shocked the reader with tables of data showing that the mortality rate of the army at rest was twice that of the civilian male population, she made her point again:

> To say that the mortality in the guards is double that of civil life is to make an understatement of the truth. It is more nearly treble. For the army mortality merely shows the deaths among those staying in the service long enough to die in it. It does not show the deaths among those discharged to die elsewhere. A low mortality, therefore, may imply not a high state of health, but a high rate of invaliding ... For if every man likely to die were invalided, the army would appear immortal, for not a man in it would ever die [30].

Nightingale highlighted the overcrowding in the barracks by reporting the cubic space allotted to one man at various barracks up and down England. She commented that the so-called “new and splendid hospital” in Portsmouth (as described by the director general) allowed only half the cubic space necessary and described some of its worst features, including the lack of bathing facilities. But there was worse to come; apparently the space at Chatham, per person, was even less and there were similar horror stories at Brompton and Fort Pitt [30]. This work of Nightingale’s resulted in substantial reform of the way British barracks and military hospitals were constructed, as well as in the diet and provision of medical and nursing services for those in the army [15].

Nightingale commented at length on the validity of the statistics and calculated what she thought would be the mortality rates if those dying after having been invalided were considered. She even attempted to put a cost to the country on this premature invaliding. Having done this she provided a new method for calculating the mortality by including the invaliding and the fact that at the start those selected for service excluded the sick. With these new measures she stated that the “real annual mortality percent of the foot guards, after correction, is 26 annual deaths to 1000 living, whereas the mortality of the male population, at the same ages, is about 9 annual deaths to 1000 living” [30]. A concerning disparity!

Nightingale then listed what data needed to be collected and how it should be presented to give an accurate picture of the health of the army. She attributed the current misleading information to a misguided belief that those reporting this data thought that they might be blamed for the state of the army, instead of everyone being obliged to them for having portrayed an accurate state of affairs [30].

As well as the lengthy discussions and commentary on mortality rates, collection of data and commentary on poor numerical skills of government officials that pepper the report, she still had enough material for an entire chapter entitled “Notes on the Inaccuracy of Hospital Statistics and the Necessity of a Statistical Department”. In this chapter, Nightingale bemoaned the woeful inaccuracy of recording details of patients, something which had upset the relatives of the sick and the dead. She pointed out that by only counting the soldiers in hospital on one day per week many soldiers were missed from these returns. The nature of diseases such as cholera meant that soldiers could enter the hospital and die between counts and so not be registered as being there. Consequently she estimated that hospital records in the Crimea may have only shown one seventh of the cholera cases. She called for standardisation and explained that for the purposes of accurate comparison it was essential to have a standard measure of time and numbers under observation [30].

This chapter in her report included several excerpts of letters from Dr. Hall (a British military surgeon serving in the Crimea) to Lord Raglan (Commander-in-Chief during the early part of the conflict) which put a very positive gloss on the numbers of deaths and the mortality rate. Unsurprisingly, Nightingale also produced her own compilation of the mortality rates from various sources, showing a marked discrepancy in the data. Later she wrote, “I have carefully compared the statistics from six different official sources, and none of them agree”. She stressed that this discrepancy “shakes [one’s] confidence” in their accuracy [30]. This is something that I am sure many analysts working with data today can identify with.

She pointed out that Dr. Hall did not try to give a percentage per annum or record anywhere those soldiers suffering from zymotic diseases. She despaired over the "novel" methods of calculation used and described them as misleading. She followed this with an example that demonstrated on some occasions patients had not just been double counted, but, rather, counted more than six times! At one point Nightingale noted in frustration that the general hospitals in the Crimea had been "so deplorably mismanaged ... that men have come to ask the question whether it would not be better to do without them altogether?" and acknowledged that general hospitals could either become "pest houses" or "be made as healthy as any other building" [30].

Many of these themes are taken up in Nightingale's later publication *Notes on Hospitals* (1863) [34]. Here Nightingale explained her view that mortality statistics gave little information on the efficiency of a hospital performance. *The Lancet* commented favourably on this publication, describing Nightingale as having "a great command over terse phrases, which she uses with telling effect, sometimes almost to the dismay of those whose souls are attuned to the sober diction and brown-suited dullness of the treatises which have appeared on such subjects up to this time" [13].

From her letters and writings, it is clear that Nightingale was keen to encourage hospital officials to understand the importance of the correct use and necessity for accurate reporting of statistics. In 1860 Nightingale sent a proposal to the ISC, held in London, advocating the uniform collection of hospital statistics, so that outcomes could be compared by hospital, region, and country. This proposal was endorsed with further measures for improving the statistics of surgical operations being validated at the ISC in Berlin in 1863 which took the analysis a step further [16]. Another substantial result of Nightingale's work was the reorganisation of army medical statistics and the setting up of a statistical branch of the Army Medical Corps [1].

As we have seen, much of Nightingale's commentary and ideas were ahead of her time. The statistician Sir David Speigelhalter said that "she clearly foresaw by 130 years, the major problems cited by clinicians ... inadequate control for the type of patient, data manipulation and the use of a single outcome measure such as mortality" [37].

11.5 Focus on India

> I have a 'melancholy satisfaction' in recording that there is one government office worse organised than the War Office, and that is the great India House [31].

Nightingale did not concern herself with statistical and health reform only in Britain. As a result of the success of the Royal Commission on the Sanitary Condition of the Army in Britain, she was allowed to be instrumental in helping to arrange the 1859 Royal Commission that was sent to India to investigate and report on the sanitary state of the army stationed there [39]. This was an unusual accolade for a woman at that time. She took a critical interest in the statistics produced by the Indian hospitals. In a letter in 1864 to Charles Hathaway (a special sanitary commissioner for Calcutta) she wrote:

> I could not help laughing at *your* critics who 'exclude' specific diseases such as 'cholera', accidents 'proving fatal' etc. It is very convenient indeed to leave out all deaths that *ought not* to have happened, as *not having* happened. And it is certainly a new way of *preventing preventable* mortality to omit it altogether from any statement of mortality, Then they would 'exclude' 'deaths above 60.' Their principle, if logically carried out, is simply to throw out all ages and all diseases and then there would be no mortality whatever . . . [38].

Again, this is a delightfully understated and pithy comment that nonetheless makes a very powerful point.

In a letter to Lord Stanley at the Liverpool Record Office in 1865, Nightingale was still concerned about the diminution in mortality but referred to the Indians as "wading and wandering through all the discrepancies of ill-kept statistics" and acknowledged that British military statistics were in a similar mess before it had been possible to "establish reliable statistics" [38]. However, by 1869, in a letter to C. C. Plowden (a clerk in the India Office), Nightingale was much more complimentary. On returning the proofs of the annual report on the measures adopted for sanitary improvements in India, she said that despite reading them "with the utmost desire to criticize" she "cannot do so at all". She concluded by saying that she was sure Plowden would be glad that she had "so little to say on this occasion" [39].

Her involvement in analysing the data for the Royal Commission on the sanitary state of the army in India ultimately led to massive reforms in the administrative processes employed there [15]. Nightingale continued to pay close attention to issues of health and politics in India for the rest of her life and health projects in India were still the subject of many of her letters written and received during her 80s. She lobbied for Indian self-rule and continued setting up various schemes that encouraged the education of Indian women, as well as emphasised the importance of clean water, good drainage and the avoidance of overcrowding [1].

11.6 Nightingale's Goals

> The main end of statistics should . . . be to enable immediate steps to be taken to prevent the extension of disease and mortality [33].

As well as writing her report on the Crimea and investigating the mortality rate of the British Army at rest in the UK and India, Nightingale was staunchly interested in educating the working classes. She wrote several papers and publications on the topic, including *Notes on Nursing: what it is and what it is not* [32] and *Notes on Nursing for the Labouring Classes*. In the latter, there is a section on the problems for life insurance societies of using averages as "they seduce us away [first edition] from minute observation" [33]. What Nightingale was emphasising here is that it is not enough to know that 2.2–2.4% of London's population die each year in order to estimate how likely it is that a particular person will die. She explained that it is only when we drill down into the minutiae of the observations and find out which district someone resides in, and even which street and house, and then make enquiries into the conditions therein, that we can make some kind of prediction as to which families are most likely to suffer sickness and death [33].

She was a keen commentator on, and reformer of, Victorian workhouses. The Liverpool workhouse pioneered the use of trained nurses [1] as a result of a request to Nightingale from the philanthropist William Rathbone. However, according to Nightingale, the misleading use of statistics brought damage to the notion of training nurses. In a note to Charles Langton from Liverpool in 1868, she commented "I cannot help feeling that much injury has been done to the cause by putting forward figures at all as a test of nursing efficiency" [17]. She argued that hospital statistics should only represent the results of different operations and varying modes of treatment and that in Liverpool they "represent nothing, because they have never been kept with reference to any result". She concluded by saying that these figures could not show the efficiency of nursing as the trained nurses look after the more severe cases and thus their patients will inevitably have a higher mortality. This comment on the use of data to measure performance is as relevant nowadays as it was then.

In the last twenty years of her life, after many of her colleagues and collaborators, such as Sidney Herbert and Dr. Sutherland, and immediate members of her family, including her sister, had passed away, Nightingale concentrated her efforts on several projects concerned with improving the health care in rural Britain. In a letter to Frederick Verney (Nightingale's nephew by marriage) in 1890, she remarked favourably on a report from Norfolk exclaiming that the county deserved the newly instituted Victoria Cross for sanitation as they had had a surprisingly low number of deaths from diarrhoea compared to their figures from ten years before [17]. High praise indeed!

According to McDonald [18], one of the last projects that Nightingale took on towards the end of her life was the attempt to establish a Chair of Social Physics (Statistics) at Oxford in memory of Quetelet. The idea of this Chair was to provide the means of continuing the work in this area and, better still, introducing it to those who could best make use of it in society. It was first proposed in her essay on Quetelet's death in 1874, but the serious work was not carried out until 1890–91. Nightingale worked closely on this project with Benjamin Jowett—a theologian, past Vice Chancellor of Oxford and very close friend. However, despite Nightingale and Jowett's lobbying, the proposal was unfortunately turned down by the Oxford authorities owing to the subject not having a Final Honour School (final university examination) [1]. Regardless of this, in 1891, Oxford did appoint a statistician, Francis Ysidro Edgeworth, to a Chair, although this was a Chair in Political Economy rather than Statistics [10]. Edgeworth went on to receive the Royal Statistical Society's (RSS) Guy Medal in 1907 and served as the President of the RSS during 1912–14. There are now numerous Professors of Statistics in the UK, including Sir David Spiegelhalter, who was given the Winton Chair of Public Understanding of Risk and Uncertainty at the University of Cambridge in 2007, with an explicit role in communicating the subject to the general public. There can be no doubt that Nightingale's work, bringing statistics into the public domain, helped to contribute to the acceptance of statistics as a worthwhile academic subject in its own right.

11.7 Conclusion

This chapter has demonstrated that as well as being known primarily for her contribution to nursing, Nightingale played an extraordinary and pivotal role in general hospital and health management reform. Her creation of infographics to tell a data-driven story and the subsequent use of these diagrams and tabulated data to influence policy and decision makers was unusual in her time, especially for a woman of her social standing. As a result of her diagrams representing mortality data, government statistics were never the same again. Indeed, her easy-to-visualise charts were taken up subsequently in the routine publication of census and other data [2, 15].

Nightingale was instrumental in the establishment of a Royal Commission to investigate the health of the British Army in England and then played an even more pivotal role in arranging a subsequent Royal Commission to India to advise on sanitation.

Her guidelines on the collection of hospital statistics were ratified by the ISC, and this and her work comparing the mortality rates of the army at rest with the civic male population paved the way for new guidelines concerning the construction of new barracks and hospitals. These, in turn, played a major role in improving the health of the armed forces and gaining Nightingale recognition as a statistician.

In conclusion, it is obvious, just from the excerpts presented in this chapter (which are only a small fraction of those that could have been chosen), that Nightingale's analytical work was helping government and the armed forces to make better decisions. This fits within today's standard definition of Operational Research, a discipline generally regarded as having come into existence after the second world war, making her a pioneer of this branch of mathematics long before the term itself had been coined. Her use of data visualisation, cleaning, organisation and analysis also marks her out as one of the earliest data scientists.

References

1. Bostridge, Mark. 2008. *Florence Nightingale*. London: Penguin Books.
2. Cohen, I. Bernard. 1984. Florence Nightingale. *Scientific American* 250(3): 128–136.
3. Cook, Edward. 1913. *The Life of Florence Nightingale*. Vol. I. London: Macmillan.
4. Cullen, Michael J. 1975. *The Statistical Movement in Early Victorian Britain: The Foundations of Empirical Social Research*. Barnes and Noble: New York.

5. Diamond, Marion, and Stone, Mervyn. 1981. Nightingale on Quetelet. *Journal of the Royal Statistical Society. Series A (General)* 144: 66–79.
6. Dossey, Barbara. 1998. Florence Nightingale. Her Crimean Fever and Chronic Illness. *Journal of Holistic Nursing* 16(2): 168–196.
7. Farr, William. 1857. Letter from William Farr to Florence Nightingale quoting Goethe. British Library 43398/14. http://www.uoguelph.ca/~cwfn/archival/index.htm. Accessed 29 October 2016.
8. Farr, William. 1861. Letter from William Farr to Florence Nightingale. British Library 43399/6. http://www.uoguelph.ca/~cwfn/archival/index.htm. Accessed 29 October 2016.
9. Friendly, Michael. 2009. Milestones in the history of thematic cartography, statistical graphics, and data visualization. http://www.math.yorku.ca/SCS/Gallery/milestone/milestone.pdf. Accessed 29 October 2016.
10. Gittins, J. 2013. Oxford University Department of Statistics: A Brief History. https://www.stats.ox.ac.uk/_data/assets/pdf_file/0005/9689/History_of_Statistics_Department.pdf. Accessed 30 October 2016.
11. Katz, William. 2012. *Designing Information: Human Factors and Common Sense in Information Design*. Hoboken: John Wiley and Sons.
12. Knopf, Edwin. 1916. Florence Nightingale as Statistician. *Publications of the American Statistical Association* 15(116): 388–404
13. Lancet, 1864. Relative Mortality in Town and Country Hospitals. *The Lancet*. February 27.
14. Magnello, Eileen. 2007. Victorian vital and mathematical statistics. *BSHM Bulletin: Journal of The British Society for the History of Mathematics* 21(3): 13–37.
15. McDonald, Lynn. 1998. Florence Nightingale: Passionate Statistician. *Journal of Holistic Nursing* 16: 2. http://www.uoguelph.ca/$\sim$cwfn/short/statistician.htm. Accessed 29 October 2016.
16. McDonald, Lynn. 2001. Florence Nightingale and the Early Origins of Evidence-Based Nursing. *Evidence-Based Nursing*. Vol. 4. http://ebn.bmj.com/content/4/3/68.full.html. Accessed 29 October 2016.
17. McDonald, Lynn. 2003. *Florence Nightingale on Society and Politics, Philosophy, Science, Education and Literature*. Ontario: Wilfred Laurier University Press.
18. McDonald, Lynn. 2003. *Florence Nightingale on Public Health Care*. Ontario: Wilfred Laurier University Press.
19. McDonald, Lynn. 2010. *Florence Nightingale: The Crimean War*. Ontario: Wilfred Laurier University Press.
20. McDonald, Lynn. 2013. The Collected Works of Florence Nightingale (archives). http://www.uoguelph.ca/~cwfn/archival/index.htm. Accessed 29 October 2016.
21. McDonald, Lynn. 2016. The Collected Works of Florence Nightingale. http://www.uoguelph.ca/~cwfn/index.htm. Accessed 30 October 2016.
22. Nightingale, Florence. 1828. Letter to Grandmother. Wellcome 8991/3. http://www.uoguelph.ca/~cwfn/archival/index.htm. Accessed 29 October 2016.
23. Nightingale, Florence. 1830. Letter to Parthenope Nightingale. Wellcome 8991/3. http://www.uoguelph.ca/~cwfn/archival/index.htm. Accessed 29 October 2016.
24. Nightingale, Florence. 1847. Letter to Parthenope Nightingale. Wellcome 9016/17. http://www.uoguelph.ca/~cwfn/archival/index.htm. Accessed 30 October 2016.
25. Nightingale. Florence. 1856. Letter to John Henry Lefroy. Wellcome 5479/6. In McDonald, Lynn, 2010. *Florence Nightingale: The Crimean War*. Ontario: Wilfred Laurier University Press.
26. Nightingale, Florence. 1857. Letter to Sydney Herbert. Wiltshire County Record Office, Pembroke Collection 2057/F4/66. In McDonald, Lynn, 2010. *Florence Nightingale: The Crimean War*. Ontario: Wilfred Laurier University Press.
27. Nightingale, Florence. 1858. Letter to Lady Harriet Ponsonby. Wellcome 9002/5. http://www.uoguelph.ca/~cwfn/archival/index.htm. Accessed 29 October 2016.
28. Nightingale, Florence. 1858. Letter to Parthenope Nightingale. Wellcome 8997/78. http://www.uoguelph.ca/~cwfn/archival/index.htm. Accessed 29 October 2016.

29. Nightingale, Florence. 1858. *Mortality of the British Army, At Home, At Home and Abroad, and During the Russian War as compared with the mortality of the civil population in England*. London: Harrison and Sons.
30. Nightingale, Florence. 1858. *Notes on Matters Affecting the Health, Efficiency and Hospital Administration of the British Army*. London: Harrison and Sons.
31. Nightingale, Florence. 1859. Letter to Sir Charles Trevelyan (governor of Madras). In Vallee, Gerard. 2006. *Florence Nightingale on Health in India*. Ontario: Wilfred Laurier University Press.
32. Nightingale, Florence. 1860. *Notes on Nursing: What It Is and What It Is Not*. London: Harrison and Sons.
33. Nightingale, Florence. 1861. *Notes on Nursing for the Labouring Classes*. London: Harrison and Sons.
34. Nightingale, Florence. 1863. *Notes on Hospitals*. London: Longman, Green, Longman, Roberts and Green.
35. Nightingale, Florence. 1864. Letter to William Farr. Wellcome 5474/74. In McDonald, Lynn, 2011. *Florence Nightingale on Wars and the War Office*. Ontario: Wilfred Laurier University Press.
36. Panmure. 1857. Letter to Florence Nightingale. In *Notes on Matters Affecting the Health, Efficiency and Hospital Administration of the British Army*. London: Harrison and Sons.
37. Spiegelhalter. David, J. 1999. Surgical Audit: Statistical Lessons from Nightingale and Codman. *Journal of the Royal Statistical Society. Series A (Statistics in Society)* 162(1): 45–58
38. Vallee, Gerard. 2006. *Florence Nightingale on Health in India*. Ontario: Wilfred Laurier University Press.
39. Vallee, Gerard. 2007. *Florence Nightingale on Social Change in India*. Ontario: Wilfred Laurier University Press.
40. Wellcome Library, London. 2016. The Collections at the Wellcome Library. http://wellcomelibrary.org/collections/. Accessed 30 October 2016.